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SOME STUDIES REGARDING THE BIOLOGY OF BUDS AND TWIGS IN WINTER.[1]

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(WITH EIGHT FIGURES)

DURING the winter months in temperate and arctic climates, the meristematic tissues of shrubs and trees assume a more or less completely dormant or resting condition, and become separated from the surrounding atmosphere by tissues of varying thickness and varying degrees of resistance to the passage of water vapor. A detailed study of these structures during the cold period has brought out many interesting facts ordinarily escaping casual observation.

In the twigs the cells of the cambium lie close together without intercellular spaces, but the cortical cells usually do not touch at the corners, and consequently in the cortex there is a more or less elaborate system of intercellular spaces. The main structural protective measure seems to be the firm epidermal layer with heavily cutinized outer wall, which is always present at this period.

There were no stomates on the twigs in any of the species I examined. Gas diffusion takes place mainly through the lenticels; but perhaps to a slight extent also through the cuticle itself. All the living cells contain a large amount of water, 51–55% in most fruit trees, 63% in Forsythia, and the quantity in each species is remarkably constant, rarely varying more than four to five per cent., and usually even much less.

Regarding the time during the previous summer when the bud fundament is first distinguishable, ALBERT[2] found that, out of

[1] Contributions from the Department of Botany of Cornell University. No. 105.

[2] ALBERT, P., Beiträge zur Entwickelungsgeschichte der Knospen einiger Laubhölzer. Forstlich-naturw. Zeitschr. 3:345, 393. 1894.

15 species of trees bearing scaly buds, the first leaf fundament in one (*Betula alba*) was present as early as May, in three at the beginning of June, in eight at the beginning of July, in two August 1, and in one not until September. The flowers were always formed later than the leaves. Some of the naked buds he found to start early in the previous season (Elaeagnus, Cornus); others, as for instance *Robinia Pseudacacia*, did not start until the spring of the year in which they were to unfold. He found that in general the buds were further progressed at the beginning of the winter the farther north the plants were native.

BEHRENS[3] found that in fruit trees the flowers are first distinguishable at a later date, as for example, in the cherry during July, and in the pear about August 11.

My own observations lead me to believe that in many cases the fundaments are present quite early. The buds of the peach were well formed July 15, and small buds were evident in the leaf-axils of forest trees as early as June 1. This suggests that, in some cases at least, the bud fundament may be present as early as the unfolding of the previous winter's buds.

Those that start quite early have usually reached an advanced stage in development by the time cold weather overtakes them in the fall. The rudimentary flower or shoot for the next season, together with all its organs, is present in the buds of some species, as for instance in the horsechestnut; while in others a varying number of nodes and internodes are thus stored. To inclose so elaborate a structure a certain number of leaves have been modified into scales which closely overlap, or are firmly cemented together at their edges around the young shoot. Such buds are found especially upon trees and shrubs with definite annual growth. The scales are usually composed of several layers of parenchymatous cells with intercellular spaces, moderately firm and slightly cutinized epidermis, on the inner side, and a very strong heavily cutinized outer epidermis, usually supported by mechanical tissue of varying amount beneath.[4] The parenchymatous cells of all or

[3] BEHRENS, J., Entwickelung und Bau der Blütenknospen unserer Obstbäume und Obststräucher. Gartenflora **47**: 269. 1898.

[4] For published descriptions of bud structure see: BEHRENS, J., *l. c.*; FEIST, A., Ueber die Schutzeinrichtungen der Laubknospen dicotyler Laubbäume während

all but the outermost scales are living and contain a large amount of water throughout the winter. The inner scales are frequently almost destitute of epidermal thickenings and are quite green and fresh. Because of the much larger size of the cells in the scales, and much larger vacuoles, there is much more water present in these structures than in the young shoot whose cells are small and nearly filled with protoplasm. This it will be seen is an important consideration when the buds freeze during the winter. The absolute amount of water in the whole bud is however very nearly the same as that in the young bark, being about 51 to 55% for the fruit buds examined; and, as in the bark, this amount is remarkably constant for the species.

The proportion of space occupied by the young shoot varies with the species and nature of the bud. In flower buds this proportion is usually greater than in leaf buds. In many cases only a very small fraction of the total volume is shoot-tissue, all the rest being composed of scales; but in other cases, as for instance the flower buds of pine, almost the whole volume is made up of cones, leaves, and stem; while the scales are very thin, dry, and firmly cemented together. In this case of course nearly all the water is located within the young shoot. The spaces between the various organs and scales usually contain air alone; but in some cases, as for example in apple and horsechestnut, there is also a large amount of wool present in which the organs are seemingly imbedded. In Populus and some other trees the spaces are more or less completely filled with resin.

Buds of most indefinite growers differ from those of the majority of definite growing trees in two essential ways: in the slight development of the fundament, and in the usual absence of scales. The young shoot is most frequently represented merely by a growing

ihrer Entwickelung. Nova Act. Leop. Carol. Ak. Naturf. **2**: 303–344, 1887, Ref. Bot. Centralb. **36**:43. 1888; SCHUMANN, C. R. G., Anatomische Studien über die Knospenschuppen von Coniferen und dicotylen Holzgewächsen. Biblioth. Botan. 15:32. Cassel, 1889, Ref. Bot. Centralb. **42**:275. 1890; GRÜSS, J., Beiträge zur Biologie der Knospen. Jahrb. Wiss. Bot. **23**:637. 1892; LUBBOCK, J., On buds and stipules. Jour. Linn. Soc. **30**:463–532. 1895; **33**:202–269. 1897; CADURA, R., Physiologische Anatomie der Knospendecken dicotyler Laubbäume. Breslau, 1887, pp. 42; MIKOSCH, K., Beiträge zur Anatomie und Morphologie der Knospendecken dicotyler Holzgewächse. Sitz. König. Akad. Wiss. Wien Math. Wiss. Kl. **74**[1]:723–755. 1877.

point without well-developed lateral organs, and can therefore be protected more economically by being sunk in a pit produced by a ring-like growth of cortex and cork, as is commonly the case. This pit is then closed at the mouth by an ingrowth of the cork itself, as in Gleditschia, or by a feltlike mass of hair, as in Robinia and other species.

In the case of the large buds with the shoot considerably advanced in growth, the bud-scale method seems the only feasible way of covering them. Another advantage in this method lies in the telescopic expansion of which scaly buds are capable early in the season while unfolding. Growth is thus permitted, but at the same time the protective qualities are not lost. In the maples and horse-chestnut the tube formed by the enlarged scales often reaches the length of 2 to 8^{cm}. By this means buds may open early in the spring and still be protected from excessive transpiration. Scaleless buds usually remain nearly dormant until later in the spring when the weather conditions are not so severe.

PHYSICAL PHENOMENA OF BUDS AND TWIGS WHEN NOT FROZEN.

The scaleless buds of the indefinite growing trees and shrubs grow very little before or during the winter. In the autumn the very limited growth is soon stopped by the advent of cold weather, and from this time until late spring scarcely any change can be detected. With the scaly buds however it is otherwise. From the inception of the fundament in July or June until cold weather there is a very considerable growth resulting in the buds of various sizes found upon the different species of trees during the winter. Little accurate work has been done towards determining the characteristics of this growth, but the results obtained in our laboratory by W. M. MORGAN during the fall of 1901 seem to show that in the case of fruit trees the growth is very uniform and gradual up to about November 15. In some cases slight fluctuations occurred which could not be accounted for, and in one or two instances these seemed periodic; but on the whole there appeared neither acceleration nor retardation until the time mentioned, when the increase in size ceased quite abruptly. From the middle of November until March 1 there was no growth in peach buds, the curve remaining almost exactly horizontal and fluctuating very little. On March 23,

several days of warm weather occurring, the peach buds began to grow rapidly and uniformly until April 23, one month later, when they came into flower. With the apple and apricot the results were very much the same. Growth almost ceased November 15, and from this time until March 1 the increase was apparent but exceedingly slight, amounting to only ½ to 1%. Renewal of activity began March 1, and from this time until April 23, seven weeks later, when the apricots flowered, and eight weeks later, when apple buds opened, the growth was very rapid. The curve after growth began was not so gradual as in the peach, but became much accelerated just before the flowers appeared.

Mr. MORGAN'S observations were as a matter of fact quite extensive, but only the above summary can be given here. At intervals of one week through the fall, winter, and spring, buds were taken from the same tree and as nearly as possible from shoots of the same vigor, a large number were measured, and the average taken as representing the size at that time. It was found impracticable to measure the same bud at different times, owing to the difficulty of manipulating the micrometer out of doors on very cold days, as well as to the fact that the measurements were liable to be taken at different temperatures each time. A Zeiss cover-glass measurer was found the most convenient instrument for the work. From the tables thus made a great many curves were plotted representing the changes in various fruit trees. The results, however, agreed very well, and in the peach, apricot, and apple were as stated above.

From these careful observations, therefore, contrary to the general belief, it seems that fruit buds at least do not grow to any extent in winter. Their swelling period is confined in the north to a few weeks just previous to the opening of the bud. Regarding our forest trees and shrubs no accurate work seems to have been done toward the determination of their curve of growth. From casual observations, I am inclined to believe that a majority will be found to agree with the fruit buds. This seems to be true of the sugar maple, whose buds are practically as large in November as in early March, also of the ash, oak, etc. On the other hand, the buds of a few plants, as, for instance, *Salix discolor*, *Ulmus fulva*, and *Ulmus scabra*, seem to increase in size early in February. However, actual measurements are necessary to determine these points.

KÜSTER[5] found that during a specially mild winter the buds of maple did show a very slight growth both in the lateral organs and in the young axis. No new organs were started either in maple or other species examined, except rarely in *Alnus cordifolia*.

ALBERT[6] found that practically all buds became dormant soon after leaf-fall until spring again. The first change in spring was a stretching of the tissues, further development of the parts taking place only later.

It is a known fact in physics that the amount of heat absorption varies, among other factors, with the color of the body investigated. In other words, the same body if colored differently will absorb a varying amount of heat from a constant source, depending upon the color. Winter buds and branches are in many cases highly colored, and the question naturally arises as to how this affects the heat absorption of the bud during the winter and spring months.

Regarding the extent to which color will affect heat absorption, in addition to the records in works on physics, the experiments of WHITTEN[7] are interesting. He found that thermometer bulbs wrapped in muslin of different colors, green, purple, black, and white, or with pieces of muslin of these various colors spread over them, or with the bulbs coated with a wash of similar colors, showed a marked difference in reading when exposed to bright sunlight. The average difference between the black- and white-washed bulbs was 16°, between the white and purple 15°, and between the white and green 13°. At one time a difference of as much as 21° between the white and purple bulbs was found.

However, the actual experiments with buds have been rather few and the results are not so definite as one might wish. The most elaborate were those of WHITTEN described in the above-cited report. He selected a row of peach trees containing several varieties, and whitewashed them during the winter. During warm days of the unusually changeable winter the unwhitened buds swelled considerably, and during subsequent cold spells most of

[5] KÜSTER, E., Ueber das Wachsthum der Knospen während des Winters. Beitr. Wiss. Bot. (FÜNFSTÜCK) 2:401. 1898.

[6] ALBERT, P., Beiträge zur Entwickelungsgeschichte der Knospen einiger Laubhölzer. Forstl.-naturw. Zeitschr. 3:345–376, 393–419. 1894.

[7] WHITTEN, J. C., Winter protection of the peach. Bull. 38. Missouri Agric. Exp. Station, April 1897.

them were killed. The unwhitened buds swelled and grew perceptibly before any swelling could be detected in those that were whitened. The difference in size March 20 was plainly shown in drawings of the sections of the two classes of buds. Whitened trees came into bloom about one day later than unwhitened trees of the same variety. In 1896–97, owing to a more moderate spring, the difference in time of flowering was still greater. The whitened buds of each variety opened two to six days later than those that were not whitewashed.

The differences in the actual time of flowering, however, does not express the difference in time of the swelling of the buds. The whitewashed buds did not begin to swell until almost time for the flowers of normal trees to appear, while the unwhitened ones began to swell three or four weeks earlier, as shown by the drawings above mentioned.

These experiments of WHITTEN seem to show that in the peach, at least, the dark-purple color of the buds tends to cause earlier activity in the spring, accompanied by earlier swelling and flowering. The only doubt, it seems to me, lies in the effect of the whitewash upon the growing tissue. As mentioned below, some nonporous substances seem to retard respiration perhaps to such an extent that growth also is retarded, but the whitewash would seem porous enough to escape this criticism. In a more recent paper WHITTEN[8] has shown that the temperature within whitened and unwhitened twigs differs by several degrees. In bright sunlight the difference was as much as 15° C., the unwhitened being the warmer. The whitened twigs were nearly of the same temperature as the atmosphere.

WHITTEN[9] has also shown that purple peach twigs transpire considerably more than green ones. This was probably due to the greater temperature and is probably an additional factor in the winter-killing of the peach.

[8] WHITTEN, J. C., Preventing frost injuries by whitening. Pacific Rural Press **60**:276. 1900.

[9] WHITTEN, J. C., Das Verhältnis der Farbe zur Tötung von Pfirsichknospen durch Winterfrost. Inaug. Diss. Halle. 1902. p. 35. See also in this connection MACOUN, W. T., Some results of experiments in spraying, etc. (whitewashing to retard bud development.) Ontario Fruit Growers Ass. Rep. **1899**:100, and "Experimental Farms," Canada, **1899**:92.

Wishing to determine the effect of natural color and surface of buds upon the absorption of heat, I carried through several experiments with horsechestnut buds, which gave some interesting results as follows.

On February 8, in bright sunshine, a large horsechestnut bud was obtained and the scales dissected away, care being taken that they were not unnecessarily injured. Two thermometers previously tested as to accuracy were obtained, and over the bulb of one the bud scales were carefully imbricated and firmly held in place by a few turns of black thread. There was enough resin present to cement the scales firmly together and thus form an artificial horsechestnut bud with the thermometer bulb in place of the normal shoot. The instruments were then placed on a table out of doors and in the shade where they were allowed to lie. As soon as the readings were nearly the same,[10] the table and instruments were carried to a place in full sunshine, care being taken that the two bulbs projected about 6.5^{cm} beyond the edge of the table so as not to be affected by direct radiation from the surface of the latter. The readings were taken as follows:

TABLE I.

Horsechestnut bulb and naked bulb, from shade out of doors to sunlight. (See *fig. 1.*)

Naked bulb	Horsechestnut bulb	Time min. & sec.	° Difference	
32° F.	32° F.	0:00	0 ° F.	(0.0° C.)
33	32	0:10	1	0.5
34	33	0:30	1	0.5
34.5	34	1:10	0.5	0.2
35	35.7	1:30	**0.7**	**0.4**
36	37	2:00	**1**	**0.5**
36	38	2:30	**2**	**1.0**
37	39	3:00	**2**	**1.0**
37	40	3:30	**3**	**1.6**
37	42	4:00	**5**	**2.8**
38	44	4:30	**6**	**3.3**
38	45	5:10	**7**	**3.9**
38	48	6:00	**10**	**5.5**
38	49	7:00	**11**	**6.1**
38	50	10:00	**12**	**6.6**
39	51	14:00	**12**	**6.6**
39	52	19:00	**13**	**7.2**
39	53	24:00	**14**	**7.7**
39	54	29:00	**15**	**8.3**

[10] They could not be made to read the same because the overcooling point in the bud had been reached.

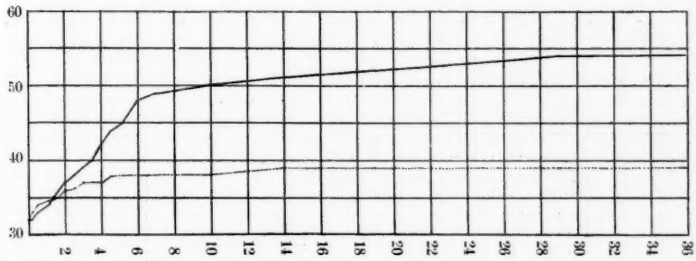

FIG. 1.———horsechestnut bulb; ..... naked bulb. Abscissas represent 5° F.; ordinates, 2 minutes. See Table I.

No further rise was noted, although the instruments remained in place more than an hour. The experiment was repeated several times during the spring, both with the same bud and with a fresh one, in every case with practically the same result, namely a much faster rise in the bud-bulb, amounting finally to an excess of 5 to 12° C. over the other bulb.

That the above differences were due mainly to the dark brown color of the bud seems probable from another series of experiments in which the naked thermometer-bulb was coated with brown drawing ink. Readings were taken under the same conditions as before. In these cases the difference was but slightly in favor of the horsechestnut bulb, probably because of the less highly polished surface of the ink bulb. It would seem, therefore, that the point is fairly well demonstrated that in the case of the horsechestnut, at least, the color does make considerable difference in the absorbing power of the bud as regards heat. Although no experiments were performed, there seems no reason why the same should not be true also of other dark-colored buds.

With these results in mind I made a few observations one spring to see if there was any relation between the color of the buds and the time of swelling and opening. It seemed reasonable to expect that the darker the bud, and consequently the more heat absorbed, the earlier the bud would swell and open in the spring; and all the more because this was the exact conclusion reached by WHITTEN with his peach experiments. Unfortunately, accurate record of the time of swelling and of opening were not kept; but still I believe

some important general tendencies can be made out from the notes, and therefore the following table is inserted:

Name	Color of buds	Time of opening
Magnolia acuminata	yellow-gray or olive	late
Ailanthus glandulosus	yellow-gray	late
Acer Negundo	pale, whitish	medium
Juglans cinerea	pale, grayish	very late
Quercus alba	gray	very late
Salix alba	yellow	early
Populus grandidentata	pale	very early
Syringa vulgaris	pale, yellowish	early
Betula lutea	olive	late
Fagus americana	olive	medium
Populus dilatata	yellow-brown	medium
Salix cordata	olive or purple	early
Salix Bebbiana	brown	medium
Salix sericea	brown-purple	early
Salix petiolaris	brown-purple	early
Acer Saccharum	bark olive-brown	medium
Tilia americana	red	medium
Aesculus Hippocastanum	dark brown	early
Acer saccharinum	red	very early
Prunus persica	purple	very early
Other species of Prunus and Pyrus	red, brown, or gray	early
Crataegus coccinea	red or dark olive	medium
Ulmus fulva	dark brown	early
Ulmus scabra	black	very early
Salix discolor	black	very early

It is not to be expected that the time of opening or even the time of swelling will in all cases be proportional to the color of the buds alone. The protoplasmic characteristics of the particular species or genus undoubtedly play a very important part; but bearing this in mind the following suggestions appear in the above table. Nearly all of the light-colored buds are also late to swell and open. None of the dark red or especially the black buds open late. On the other hand, a few light buds, as for example those of Syringa, Populus, and *Salix alba*, open quite early. This may be due to more easily aroused protoplasm than is present in most buds. Possibly if these buds were black they would open still earlier and therefore suffer injury from the frost; thus the present lighter color may serve as a means of protection.

During the spring of 1901, about March 1, some experiments were started to determine if possible whether other buds might be influenced by color in a way similar to the peach buds white-

washed by WHITTEN. Instead of whitewash, black paint was used to see if they might be made to open earlier. Two kinds of paint were prepared, one made of lamp black mixed with linseed oil, the other of lamp black and xylol. Buds and twigs of *Syringa vulgaris*, *Ailanthus glandulosus*, *Populus dilatata*, and apple were treated to a coat of oil paint; while some others of Syringa, Ailanthus, and apple were coated with xylol paint. The results were as follows:

Syringa.—Xylol-painted buds much behind the normal during vernation; they looked unhealthy, one or two being entirely dead. Oil-painted buds never began to swell, all dead.

Ailanthus.—The xylol paint made no difference with the killing back of the branches nor with the development of the buds. Oil paint prevented the swelling of the buds; they never opened.

Apple.—Xylol-painted buds much behind the others; one completely dead. Oil-painted ones all dead.

Populus dilatata.—Oil-painted buds showed much more rapid swelling than normal. When just opening the blackened buds were 6 to 8^{mm} longer.

These results are evidently in the main exactly opposite what we were led to expect. I suspect that the explanation lies in this, that the coating of the surface of the bud with paint prevented respiration, and thereby inhibited growth just as did varnish used on naked buds as described later in this paper, although it is possible that some toxic property of these substances might have had something to do with the matter. The xylol furnished a much more porous layer than did the oil, and the inhibition was therefore much less. The buds of *Populus dilatata* are normally almost completely infiltrated with resin in the spaces between the organs and on the surface, and consequently may have some other means of obtaining oxygen for respiration. The coating even with oil paint, therefore, did not injure them. On the contrary, the black color seemed to cause an acceleration in growth.

In concluding this part of the subject we may say that in the climate of New York, buds during the winter seem to remain in an almost dormant condition until a short time previous to their opening in the spring. In Missouri swelling of peach buds began much earlier than in New York.

Color through its power of absorbing heat seems to have some effect upon the growth of buds in the spring. Early buds are in

most cases dark, and artificial darkening, when unaccompanied by deleterious factors, seems to accelerate the opening.

PHYSICAL CONDITIONS IN FROZEN BUDS AND TWIGS.

From many inquiries it would seem that very few people are really sure whether free ice is actually present in buds in winter. Nevertheless, this is one of the most common phenomena connected with the winter condition of trees and shrubs. To put the matter on a firm basis of observation I undertook, during the winter of 1901, to section buds of various trees during cold periods and to determine under the microscope the amount of ice present. The method employed was as follows. Early in the morning, at about sunrise, after a fall of temperature to −18° C. or below, a table, microscope, razor, needles, slides, and cover glasses were placed in a shady situation in the open air, where they were allowed to become thoroughly cooled. Free-hand cross sections of the various buds were then made, and mounted on the slide. For a mounting medium cedar-wood oil was found best. A small quantity of this in a vial was allowed to cool with the instruments. One important advantage in the use of cedar-wood oil over those of a denser nature lay in the fact that it did not congeal at the low temperatures of the experiment. The ice remained unmelted in the preparation and could be observed at leisure; or if the thawing process was under study the slide could be carried to a warm room and placed under another microscope. The melting ice was unable to evaporate from the section, and therefore it was easy to determine whether the water was all reabsorbed, and the approximate rate of absorption.

The ice was found to occur always in broad prismatic crystals arranged perpendicular to the excreting surface; and usually formed a single continuous layer throughout the mesophyll of the scale or leaf, to accommodate which the cells were often separated to a considerable distance (*figs. 2, 3, 4*). This ice sheet was composed of either one or two layers of the prismatic crystals, depending on the water content of the adjacent surfaces, and was often as thick as the whole normal scale. The cells surrounding the ice, having lost their water content, were in a more or less complete state of collapse,

depending upon the resistance of the walls, and often occupied a space smaller than the ice itself. These cells were uninjured, however, and would resume their normal condition on thawing. In all cases more ice was found in the scale than in the young shoot; never between the scales but always in the mesophyll. The cells of the embryonic shoot were so much smaller and their water content so much less, that frequently it was difficult to detect any ice forma-

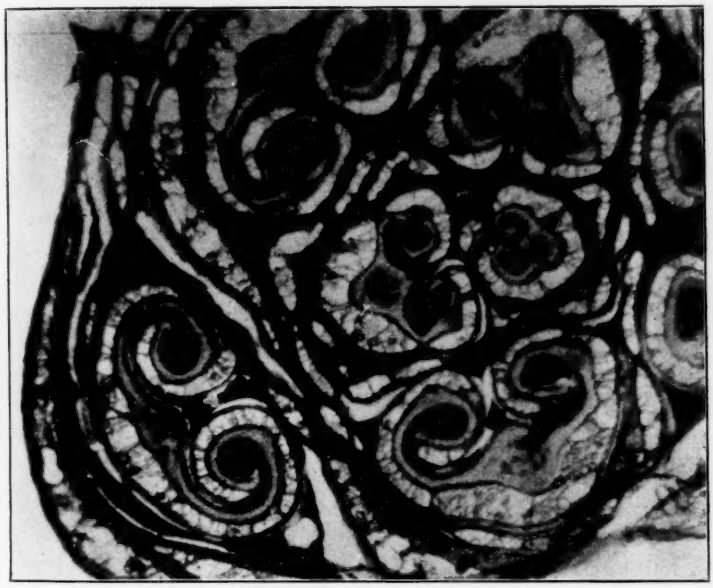

FIG. 2.—*Populus dilatata:* cross-section of bud, showing ice in bud-scales and foliage leaves.

tion whatever; but ordinarily very minute and numerous masses, at least, were scattered between the cells, and sometimes there were large masses such as appear in the outer organs. In young anthers the ice often filled almost the entire anther cavity, and in it the pollen grains were imbedded in a completely collapsed state.

The results of the observations regarding the occurrence of ice in buds may be summarized briefly as follows. The temperature was $-23.5°$ C. to $-18°$ C.

1. Tissue packed full of ice in shoot and in mesophyll of scales forming sheets parallel with the surface; rapidly and completely reabsorbed when the sections were thawed in oil. Sponging out of sections very marked.—*Populus dilatata* (*fig. 2*) and *P. candicans*, *Prunus serotina* and *P. virginiana*, *Betula lenta*, *Acer Negundo*, *Pyrus Malus* and *P. communis*, *Aesculus Hippocastanum*.

2. Containing a large amount of ice, but the water tardily reabsorbed on thawing in oil.—*Acer Saccharum*, *Tilia americana*, *Ulmus scabra*, *Crataegus punctata* (*fig. 3*).

FIG. 3.—*Crataegus punctata:* cross-section of bud, showing ice in bud-scales and floral parts.

3. No ice could be found at 0°C. Tissue dense, of small cells.—*Castanea dentata*, *Hamamelis virginiana*, *Fagus americana*, *Fraxinus americana*, *Juglans cinerea*, *Corylus rostrata*, *Quercus alba*, *Hicoria ovata*.

4. Other cases.—In *Pinus Strobus* and *P. sylvestris* there was a moderate amount of ice in the shoot and in the anther as well as in the inner scales. In *Syringa vulgaris* there was a very large quantity of ice in the scales and young shoot, especially in the anthers (*fig. 4*). In *Viburnum dentatum* and *Prunus persica* the amount of ice was small, but water was quickly reabsorbed.

Of the twenty-seven plants examined there were only eight that showed no ice in the buds at −18° C. These eight were sectioned later at −26.5° C., with the result that in Castanea, Hicoria, Fraxinus, and Juglans numerous minute ice crystals were found between the cells. It would seem, therefore, that ice may be found in all buds if the temperature is sufficiently low.

The accompanying illustrations are reproductions of photomicrographs taken by the writer during periods of low temperature.

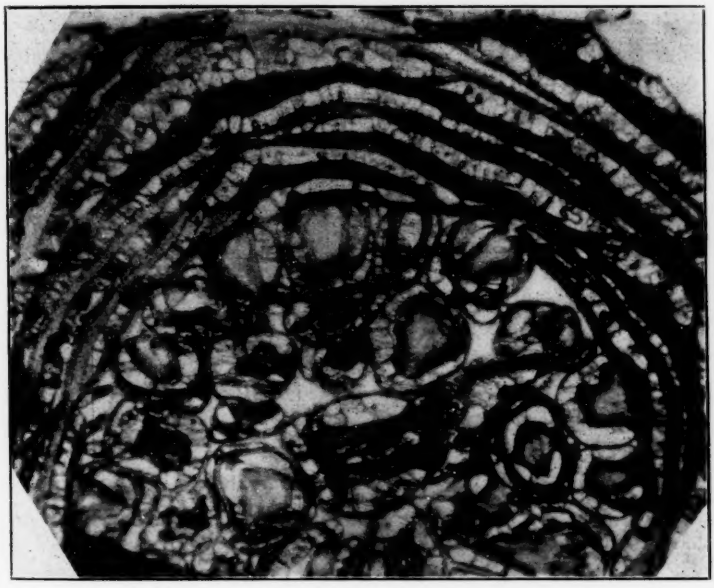

FIG. 4.—*Syringa vulgaris:* cross-section through flower bud while frozen; the light spaces filled with ice.

When the mercury registered at zero Fahrenheit or below, freehand sections mounted in oil as already described were photographed, the apparatus being set up in the open. The conditions for sectioning were so strenuous that very thin sections could not be obtained, and hence the rather poor quality of some of the photographs. The palisade-like ice prisms fill the light areas through the mesophyll of the scales and young leaves.

The question naturally arose as to the cause of the difference in ice content and why ice was absent in the eight species mentioned. Since lowering the temperature from −18° C. to −23.5° C. caused the appearance of ice in some, it would seem therefore to be simply a matter of temperature. But the degree of cold necessary to cause the separation of ice is proportional to the force which holds the water in the tissue. This in turn depends upon the relative proportion of water to cell-wall and protoplasm. We should expect, therefore, to find in those buds which are difficult to freeze a smaller amount of water than in other buds; also smaller cell-structures, since by this latter means the proportion of cell-wall and protoplasm is increased. When cells become smaller it is usually the water content that most rapidly diminishes, the protoplasm following at a much lower rate. I have made the following measurements of the cells and water content in seven of the species in which there was much ice, and in seven in which ice did not appear at −18° C.

	Max. aver. mm.	Min. aver. mm.	Text. of wall	% of water
A. Ice abundant in bud-scales, leaves, and growing point—				
Crataegus punctata	0.040	0.012	thin	49.4
Ulmus scabra	0.051	0.015	"	46.6
Syringa vulgaris	0.0045	0.009	"	53.2
Acer Negundo	0.021	0.009	"	45.9
Prunus serotina	0.021	0.015	"	47.6
Populus dilatata	0.025	0.018	"	39.3
Betula lutea	0.018	0.006	"	37.5
B. Ice not present at −18° C				
Quercus alba	0.015	0.006	thick	22.7
Corylus rostrata	0.018	0.006	"	29.7
Castanea dentata	0.018	0.015	"	25.4
Fagus americana	0.008	0.003	"	26.8
Hicoria alba	0.048	0.015	very thick	31.4
Juglans cinerea	0.012	0.003	thick	25.0
Fraxinus americana	0.021	0.003	"	29.8

Our supposition regarding the smaller size of the cells and smaller water-content in the second group, therefore, seems to be upheld by these results.

In the twigs ice is also present in very cold weather, where it may be found in three different localities. The largest quantity occurs in the cortex, where the ice crystallizes in prisms arranged

in single or double series according to the law of freezing tissues. The ice is more frequently in the form of a continuous ring, or really a cylinder, extending entirely around the twig, prying apart the cells of the cortex in which it lies. The outer cylinder of cortex in such twigs is completely separated from the inner layers when frozen. In a few species instead of the continuous layer, lens-shaped ice masses are interpolated irregularly throughout the cortex. The cortical cells after the withdrawal of the water are as completely collapsed as were those in the bud scales, but they also usually regain their normal condition on thawing. In the wood ice rarely forms in large quantities. It is usually confined to small masses in the vessels themselves, or, according to some authors,[11] sometimes extends in radial plates in the pith rays. In sectioning twigs, I myself have never seen ice in the wood elsewhere than in the vessels or wood-cells. In the pith the ice, so far as I have been able to observe, always occurs within the cells and therefore in very small masses.

At the time when the buds were sectioned, cross-sections of the twigs were made and mounted in the same manner. Ice was found in the cortex of all those in which it was present in the bud, but usually in proportionately larger quantities. It was also found in the following species which showed no ice in the buds: *Corylus rostrata*, a small amount in large clefts in the cortex; *Castanea dentata*, some ice in ordinary small spaces of the cortex but not aggregated; *Hamamelis virginiana*, a ring of ice completely around the stem in young twigs. In Fraxinus, Fagus, and Juglans none could be found, and Quercus was not investigated.

Since water on freezing increases in volume, one would at first thought expect the frozen twigs to be larger in diameter than normal. Such, however, is not the case. In every instance a distinct contraction occurred, which in some cases was very marked.[12]

[11] MÜLLER-THURGAU found ice present in the large vessels of Syringa, Cornus, and in pears, almost completely filling them; and several times he could also demonstrate it in the wood-cells. The ice was the most distinct, however, in the vessels of the grape. Ueber das Gefrieren und Erfrieren der Pflanzen. II. Landw. Jahrb. 15:481. 1886.

[12] Both SACHS and MÜLLER-THURGAU have shown that a similar contraction occurs quite generally when herbaceous tissues freeze. SACHS, J., Krystallbildung

To determine the exact amount of contraction the Zeiss cover-glass measurer was used. Pieces about 10^{cm} long of one or two year old twigs taken at −18° C. were inserted in the clamps of the machine, a record taken, and then the whole carried to the warm laboratory. The increase in size on thawing could be followed by watching the movement of the indicator as the ice melted, and when at last stationary another reading was taken. Some results are given in the following table:

	Frozen	Thawed	Difference	Exp. or contr.
Cornus stolonifera	2.58^{mm}	2.60^{mm}	0.02^{mm}	expanded
" "	3.38	3.43	0.05	"
Tilia platyphyllos	2.03	2.10	0.07	"
" "	3.18	3.30	0.12	"
Populus dilatata	3.17	3.28	0.11	"
" "	4.72	4.80	0.08	"
Acer platanoides	2.82	2.86	0.04	"
" "	3.44	3.48	0.04	"
Pyrus Malus	2.97	3.03	0.06	"
" "	3.89	3.95	0.06	"
Salix cordata	5.34	5.44	0.10	"
" "	5.80	5.94	0.14	"

Many twigs at −18° C. or below appear very much wrinkled on the surface as though dried and dead. This is especially true of the polished shoots of *Salix cordata*. On very cold mornings shoots of this species appear as though dead and dry, the bark being completely covered with fine longitudinal wrinkles. Some of these shoots were brought to the laboratory and allowed to warm, during which process the disappearance of the wrinkles could be watched with ease. In about ten minutes the twigs were entirely smooth and normal. It was from such twigs that the above readings were taken. To show more graphically the expansion during thawing, some twig-sections about 10^{cm} long were taken from the same willow and the ends while still frozen dipped in melted paraffin. The caps thus produced at the ends of the twig were in every case ruptured down the side on thawing, leaving in most cases a cleft of considerable size between the two edges. Twigs of plum were

bei dem Gefrieren u. Veränderung der Zellhäute bei dem Aufthauen saftiger Pflanzentheile. Bericht Verhand. König. Sächs. Gesell. Wiss. Leipzig, Math.-Phys. Klasse **12**: 1–50. 1860. MÜLLER-THURGAU, H., Ueber das Gefrieren und Erfrieren der Pflanzen. Landw. Jahrb. **9**: 187. 1880.

also much wrinkled, those of Negundo and apple showed a slight furrowing, those of black cherry and pear scarcely any at all.

The photographs of wrinkled twigs of *Salix cordata*, reproduced in the accompanying illustrations (*fig.* 5), were made in the open at a temperature of −20° C. The same twigs were then placed in the laboratory, and after about one hour were photographed again. The slightly wrinkled appearance in the upper shoot in

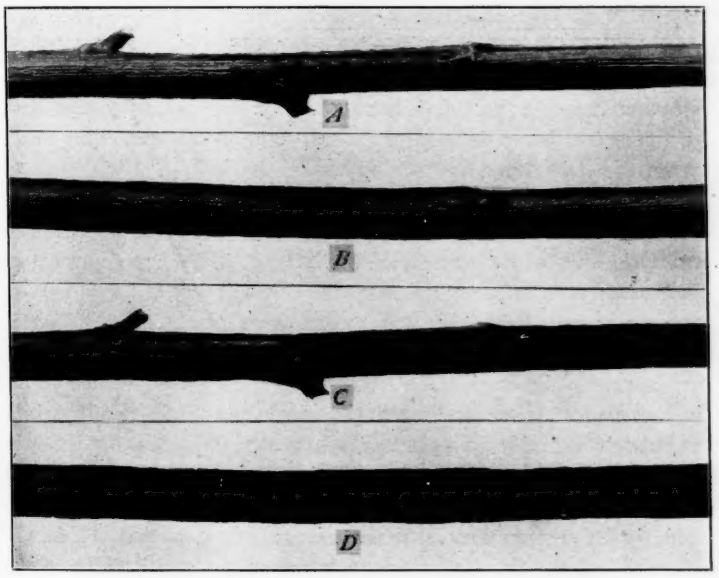

FIG. 5.—*Salix cordata: A* and *B*, twigs photographed in the open at −20° C., showing wrinkled condition due to contraction; *C* and *D*, the same twigs thawed in the laboratory; the furrows have disappeared except the minute normal striae on the lower twig.

the second photograph was normal for that shoot when thawed, during both winter and summer.

It seemed desirable to determine whether this contraction was mainly in the bark or in the wood or in both. At a temperature of −18° C. much wrinkled twigs of *Salix cordata* were collected, and the following measurements made:

With bark on twig the diameter, 7.80^{mm} expanded to 8.04^{mm} on thawing; difference 0.24^{mm}. With bark removed from a small spot for the clamps of the measuring instrument, the diameter, 5.05^{mm}, expanded to 5.15^{mm}; difference, 10^{mm}.

Therefore more than half of the total expansion was in the bark. Thickness of the bark was 0.5 ^{mm} on each side; thickness of the wood and pith, 2.05^{mm} on each side; expansion of the bark, therefore, was 13.5 per cent.; of the wood, only 2.5 per cent.

With thicker twigs, containing more hard wood, the expansion would have been still less.

Where the bark was whittled away entirely around the end of the twig and for some distance back, the expansion of the wood was not detected; probably because water had passed to the bark to freeze and being removed there was none to cause swelling again when the twig thawed.

The explanation of the contraction of twigs on freezing probably lies in the following considerations. When the water is extracted from the walls of the wood-cells, the latter contract to a slight extent just as they do when wood seasons. This accounts for a part of the shrinkage. The rest and greater part occurs in the cortex. Here the intercellular spaces are quite large and numerous, and are normally filled with air. When freezing occurs the ice forms in the spaces and the cells collapse, while the air is mostly driven completely out of the twig. The contraction in the cortex will be approximately equal to the volume of air expelled plus that of the air compressed minus the expansion of the ice while freezing. This is for contraction in all directions; only a portion of this will be radial, depending upon the structure of the particular species; much the greater part, however, is radial in all twigs.

With buds the study is not quite so easy. The record of buds measured at $-18°$ C. and then again after thawing is shown in the adjoining table.

From this table it will seem that in all cases, except in Populus and Acer, there was a decided increase in size on freezing and a consequent decrease when thawing out. In the two named cases there was a slight contraction as in the twigs. It is not quite clear why the buds should behave so differently from the twigs. The only explanation I can offer at present is that the contraction of

	Frozen	Thawed	Difference	Contraction or expansion
Cornus stolonifera	2.22mm	2.20mm	0.02mm	contraction
" "	2.66	2.61	0.05	"
Tilia platyphyllos	3.63	3.54	0.09	"
" "	3.15	3.07	0.08	"
Populus dilatata	2.77	2.77	0.00	0
" "	3.03	3.04	0.01	expansion
Acer platanoides	5.06	5.08	0.02	"
" "	4.34	4.34	0.00	"
" "	4.16	4.17	0.01	"
Pyrus Malus	4.92	4.88	0.04	contraction
" "	4.04	4.03	0.01	"
" "	4.72	4.68	0.04	"
Prunus persica	2.62	2.59	0.03	"
" "	2.50	2.46	0.04	"
" "	2.72	2.66	0.06	"
Prunus americana	2.17	2.09	0.08	"
" "	1.78	1.71	0.07	"
" "	2.10	2.06	0.04	"

the wood is eliminated, of course, and that the formation of ice tends to bow out the scales so that they stand less closely together. If the bud scales curve like leaves in freezing this result is to be expected.

When the temperature rises sufficiently, the buds and twigs thaw out and regain their normal condition. In the sections under the microscope the reabsorption was so rapid as in most cases to be entirely completed when the ice itself had finished thawing. This results in an active sponging-out movement in the sections as the cells recover from their collapsed condition (*fig. 6*). On account of the rapidity it is frequently difficult to keep the point of observation in the field of the microscope. Thawing seems not to harm these tissues in the least, no matter how frequently or how abruptly it is done. I have often tried the experiment of transporting twigs abruptly from −18° C. to the warm laboratory at 21° C. and back again several times, thus alternately thawing and freezing them. No matter how many times this was repeated no injury could be detected in the buds, even when subsequently placed in the greenhouse to grow.

Buds and twigs do not thaw at 0° C. if the rise in the surrounding temperature is gradual, as it is in atmospheric changes, but at a much lower degree. The thawing like the freezing is proportional to the temperature, and is almost if not quite completed when the

freezing point of the tissue is reached. This, in the case of buds, lies at about $-3.5°$ C. to $-2.3°$ C. Hence, if tissues which have been subjected to $-18°$ temperature in the open are to be observed with the maximum ice content, it must be while the temperature is still low. If in the morning the temperature has risen to $-7°$ C. before observations are made, very little more ice will be found than if the cooling to $-7°$ C. had just taken place.[13]

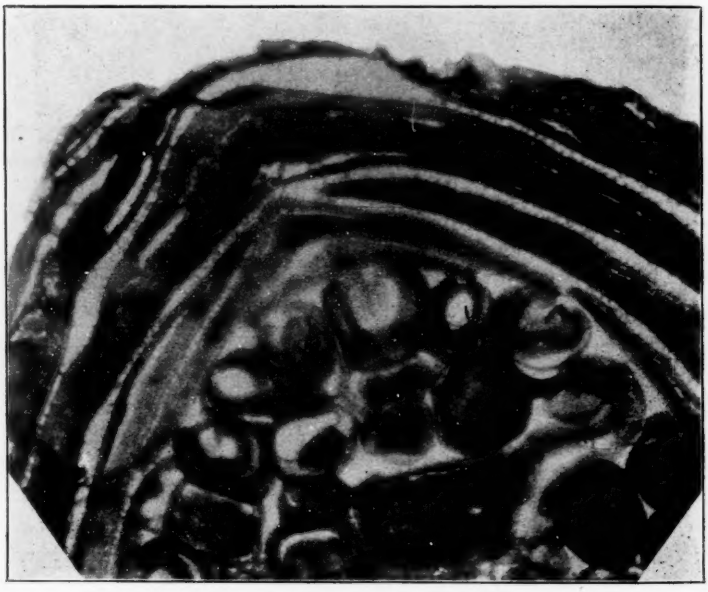

FIG. 6.—*Syringa vulgaris:* same section as in *fig. 3* thawed in the laboratory; note sponging out of tissue and closing of spaces occupied by the ice.

[13] GOEPPERT gives a similar experiment. "Twigs with buds of *Cornus mascula*, *Prunus Cerasus*, and *Aesculus Hippocastanum* were on January 2, 1871, placed ten hours at a temperature of -16 to $-20°$ C. Then while frozen stiff they were plunged into the warm tube of an oven at 25° C. and placed in water for further observation. They developed later just as others that had not been subjected to this experiment." Some other experiments with herbaceous plants led GOEPPERT to believe that in most cases alternate thawing and freezing, when taking place many times, gradually weakened the tissue. Ueber das Gefrieren, Erfrieren der Pflanzen und Schutzmittel dagegen. Stuttgart, 1883, p. 33.

WHITTEN believes that rapid thawing and freezing is very detrimental to the

WINTER FUNCTION OF BUD SCALES.

Bud scales are obviously for the purpose of protecting the tender inner shoot from detrimental external influences; but how is this protection accomplished? This is a subject regarding which opinion has varied widely and does still at the present time. I believe we shall find that the most widely accepted views, strangely enough, are not the correct ones, even though the subject appears so simple. We can conceive of such protection taking place along four lines: (1) by keeping out external moisture; (2) by preventing the penetration of cold or sudden changes of temperature; (3) by preventing the escape of internal moisture; (4) by warding off external mechanical injury. It seems best to discuss each of these in turn, and in this way determine the extent to which each one is operative.

External moisture.

There is a widespread belief that bud-scales function by keeping out the wet. The subject, however, is a difficult one to determine experimentally, and I can find no reference in literature to such experiments having been performed. Let us first determine the possible ways in which water might be supposed to injure the embryonic tissues. First, the cells might absorb too much water and thus become more sensitive to frost. It seems quite reasonable to believe that a cold spell following such an event might end the life of the bud completely. Again, through gradual absorption of the air by the water the latter might replace the air in the intercellular spaces, thus preventng free respiration. Or again, if a thawing bud were surrounded by water, the latter, instead of air, would be drawn in to fill the vacant intercellular spaces, the final result being the same as in the last case. Lastly, one might expect that the freezing of free water between the embryonic foliar and floral parts might cause mechanical injury.

purple buds and twigs of peach. Green twigs and especially whitened ones warm up less each day and this color would therefore be protective. I believe it may quite likely be true that delicate buds might suffer by such violent treatment either from stimulated activity or increased transpiration, even though hardy trees are apparently indifferent. Das Verhältniss der Farbe zur Tötung von Pfirsichknospen durch Winterfrost. Inaug. Diss. Halle. 1902.

Taking up these in turn, if the cells were so unprotected as to be capable of absorbing water in this way, they would be expected to lose a large part again when dry conditions returned, and thus quickly following frosts alone could do harm. There is also considerable doubt whether sufficient water would be absorbed by the cells to cause any perceptible difference in sensitiveness. Water at winter temperatures absorbs air very little, and especially after having fallen in the form of raindrops it may be considered as nearly saturated. The air in the leaves would probably be absorbed very little, if at all, although compression of the air due to capillarity might allow some water to enter. If the thawing tissue has its spaces filled with water instead of air, this will not necessarily cause harm. In experiments on leaves it was found that only the ivy leaf was unable to recover when the spaces were filled with water. Many leaves allow the water to evaporate and then become normal. Mechanical injury is not probable since the air spaces of the tissue would be elastic enough to overcome the compression of the expanding ice between the organs, and after the tissue froze slight pressure from the outside on the compressed cells would do no more harm than the pressure of the ice masses within ordinary tissue.

However, the greatest objection to this theory, it seems to me, lies in the fact that protection against moisture might be obtained in a much simpler manner. The embryonic tissue might be densely clothed with strigose hairs, or densely glaucous, either of which would cause the rain drops to roll off without wetting, at the same time allowing gas-interchange to continue; or a coating of resin would effectually prevent all danger of water absorption. All of these devices are more simple than the elaborate system of bud-scales found on many trees. On the other hand, the wool produced on many buds would tend directly to retard the drying of the bud surface.

The result of an experiment may here be given. During the winter of 1902, about January 24, several buds of *Acer platanoides*, deprived of their scales but still remaining on the tree, were each inserted in a rubber pipette-bulb previously filled with water. The neck of the bulb was then fastened firmly around the twig by means of twine. The experiment was allowed to continue about one

week, during which time temperatures of −23.5° C. had alternated with those of 4.3° C., so that the buds were alternately frozen and thawed. After removal of the rubber, the tissue appeared as fresh and sound as ever; the twigs were then cut and placed with their ends in water in the greenhouse, where the treated bud remained fresh as long as did others whose scales were freshly removed as check experiments.[14]

There exists, it seems to me, insufficient evidence to sustain the theory that the exclusion of external moisture has played an important part in the evolution of scaly buds.

Heat conduction.

The popular belief is widespread that bud-scales serve to keep out the cold, and indeed such an explanation appears in some of our leading textbooks and in various other works. A moment's consideration will convince us that this cannot be true. No plant tissue yet known is a perfect non-conductor of heat, or, indeed, less than a fairly poor conductor, and scale tissue is no exception; while the very thin nature of the scaly covering on some buds, as those of Salix, would absolutely preclude their offering more than a moderate amount of resistance to the escape of heat. To keep out the cold during an entire cold spell in winter would require, even in much thicker tissue, an almost absolute non-conductivity, and that is possessed by few if any substances in nature, much less by the bud-scales. This erroneous impression has arisen probably through comparing the action of bud-scales with that of clothing upon the human body, forgetting the fact that in the body there is a constant source of heat without which clothing could not keep it warm for more than a few minutes.[15]

[14] KNY found that with the bud-scales and cortex intact average twigs will not take up as much water through these organs as they give out in dry air during a similar time. He neglected, however, to experiment with naked buds. Ueber die Aufnahme tropfbar-flüssigen Wassers durch winterlichentlaubte Zweige von Holzgewächsen. Ber. Deutsch. Bot. Gesell. **13**:361. 1895.

[15] It may be suggested that such a constant source of heat does actually exist in a tree, at least so far as the buds are concerned, and that this is provided by the heat accompanying respiration. However, reference to any textbook in plant physiology will show that the amount of heat evolved in this way is but slight in the very best examples, which are all herbs, and is mainly evident during the period of most

Such substances can only retard, not prevent, the escape of heat. As a final argument we may return to the fact that observation shows that buds are always filled with ice during cold periods, which of course could not occur if they were kept warm.

It is a more difficult matter to demonstrate whether the non-conductivity of the bud-scales is of importance to the bud in any other way. Recently GRÜSS[16] has quite firmly upheld the theory that one of their chief functions is to modify the temperatures reaching the interior of the bud. We can conceive of several ways in which such protective service might occur. First, poor conductivity might prevent injury from too rapid thawing. Second, bud-scales might prevent extreme fall of temperature by preventing excessive radiation. Third, they might prevent too frequent rapid thawing and freezing due to fluctuating sunlight, and thus prevent excessive water evaporation.

Before answering any of these questions let us try to understand a little more fully the actual relation of bud-scales to heat. This problem resolves itself into two parts, namely, a consideration of the conductivity simply, and a consideration of the relation to normal atmospheric heat changes in the open.

On the question of conductivity the following experiments seem to throw some light: Two thermometers, previously tested as to their readings, were selected, and the bulb of one was covered with the imbricated scales of a fresh horsechestnut bud, as in the previous experiment to determine the effect of color, thus forming an artificial bud with the thermometer bulb in place of the young shoot. The other bulb was left naked. The experiments were all conducted within the building where the conditions were more constant and presented fewer uncontrollable factors than outside. The room

rapid growth. During the dormant winter period it must be very slight in all trees. An ordinary thermometer probably could not measure it. It may also be suggested that since the large size and mass of the trunk would retard heat changes, being warmer than the air when the temperature is falling, and cooler when the latter is rising, this, by conduction along the branches, would modify the temperatures in the shoots and buds. SQUIRES has shown (Minn. Bot. Stud. 1:453) that the average temperature in a box elder tree was in January 1.3°C. higher than the air, in February the same as the air, and in March 1° lower. The differences between internal and external temperatures during the day was in all cases only a few degrees. The idea that the branches can conduct such slight modifications so long a distance without loss is so evidently unreasonable as to require no more discussion here.

[16] GRÜSS, J., Beiträge zur Biologie der Knospen. Jahrb. Wiss. Bot. 23:651. 1892.

selected had a temperature ranging from 3.7° C. to 4.3° C. during the several days on which readings were taken. The two thermometers were brought to the same reading in a warmer place, either in another room or over a water bath, then quickly taken out and the readings recorded for every few seconds until they again registered at the same degree in the cold atmosphere of the room. Two classes of readings were taken, one from a temperature only a few degrees above that of the cold room and the other from one far higher. The readings in each class, taken with the same bud, corresponded remarkably. A specimen reading from each set is here given.

TABLE II.

Horsechestnut bulb and naked bulb transferred abruptly from a temperature of 19.5° C. to one of 3.5° C. (See *fig. 7.*)

Naked bulb	Horsechestnut bulb	Time	°Difference	Time difference
67° F.	67° F.	0 sec.	0 F. (0° C.)	0 sec.
66	67	5	1 (5.0)	20
65	67	10	2 (1.0)	20
64	67	18	3 (1.5)	37
63	66	25	3 (1.5)	45 (¾ min.)
62	65	30	3 (1.5)	50
61	65	38	4 (2.1)	72
60	65	45	5 (2.7)	60
59	64	55	5 (2.7)	75
58	63.5	60	5.5 (3.0)	95
57	63	70	6 (3.3)	100 (1⅝ min.)
56	62	80	6 (3.3)	105
55	62	90	7 (3.9)	125
54	62	100	9 (5.0)	145
52	61	110	9 (5.0)	175
50	59	130	9 (5.0)	205
49	58	155	9 (5.0)	200 (3⅓ min.)
47	56	185	9 (5.0)	255
46	56	200	10 (5.5)	285
45	55	215	10 (5.5)	340
44	54	245	10 (5.5)	375
43	52	285	9 (5.0)	420 (7 min.)
42	51	325	9 (5.0)	520
41	49	355	8 (4.4)	630
40	48	395	8 (4.4)	765 (12½ min.)
40	47	440	7 (3.9)	765
40	46	485	6 (3.3)	765
39	45	555	6 (3.3)	960
39	44	620	5 (2.7)	960
38	43	705	4 (2.1)	1235 (20½ min.)
38	42	845	3 (1.5)	
38	40	1160	2 (1.0)	
38	39	1515	1 (0.5)	
38	38	1940	0 (0.0)	

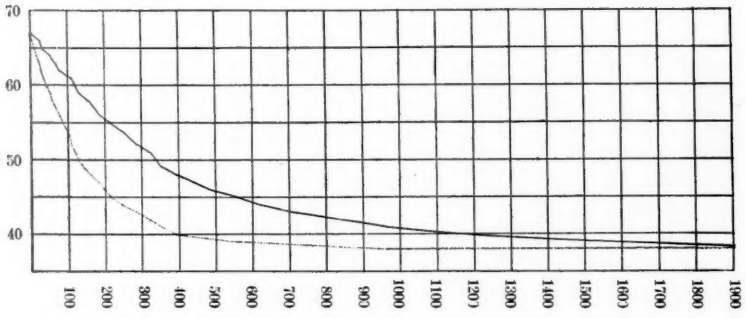

FIG. 7. ——— horsechestnut bulb; ..... naked bulb. Abscissas represent 5° F.; ordinates, 100 seconds. See Table II.

The first column of figures represents the readings in degrees from the thermometer with the naked bulb; the second column the same from the bud-covered instrument; the third column shows the time in seconds from the beginning of the experiment; the fourth column the difference in degrees at each reading; and the fifth column is the "time-difference," so-called, which represents the number of seconds elapsing after a reading on the naked bulb before the same temperature was reached on the horsechestnut bulb, in other words, the number of seconds by which the bud-scales retarded the fall of temperature in the enclosed bulb.

While not attempting to deduce the physical laws governing the fall of temperature in each case, we may note from the tables and curves several points which bear upon our problem. It will be seen that theoretically the time required for the temperature to fall in either case is infinitely long, the curve becoming nearly horizontal towards the end of each experiment. But for all practical purposes, and as closely as my instruments would measure, the fall was completed in about thirty minutes in each case. The greater part of it, in fact, was completed in ten minutes. As regards time, in Table II the very much more rapid radiation of heat more than balanced the effect of the greater quantity of heat to be radiated.

As we should expect, the retarding effect of the bud-scales in degrees, shown in the fourth column, was much greater in case of the greater extremes of temperature, and was greatest when the

TABLE III.

The same thermometers and bud preparation transferred abruptly from a temperature of 51° C. (over a water bath) to one of 2.7° C. (See *fig. 8.*)

Naked bulb	Horsechestnut bulb	Time	°Difference	Time difference
124° F.	124° F.	0 sec.	0° F. (0° C)	0 sec.
120	123	5	3 (1.5)	15
116	122	10	6 (3.3)	15
110	120	15	10 (5.5)	27
106	118	20	12 (6.6)	28
100	116	25	16 (8.8)	42
97	114	30	17 (9.4)	45 (¾ min.)
94	113	35	19 (10.5)	50
91	111	40	20 (11.1)	55
88	109	45	21 (11.6)	60
84	106	48	22 (12.2)	77.7
82	105	55	23 (12.7)	80
80	103	65	23 (12.7)	80
77	101	65	24 (13.3)	90 (1½ min.)
74	99	69	25 (13.9)	111
72	97	75	25 (13.9)	115
70	96	80	26 (13.9)	120
69	94	85	25 (14.4)	125
67	93	90	26 (13.9)	135
65	91	95	26 (14.4)	145
63	88	105	25 (13.9)	155
61	87	115	26 (14.4)	160
60	86	120	26 (14.4)	165
58	83	130	25 (13.9)	180
58	81	140	23 (12.7)	180
54	76	160	22 (12.2)	200 (3⅓ min.)
52	75	170	23 (12.7)	230
50	74	180	24 (13.3)	250
49	72	190	23 (12.7)	265
47	69	210	22 (12.2)	280
46	68	220	22 (12.2)	330
45	65	240	20 (11.1)	335
44	63	260	19 (10.5)	240
42	61	275	19 (10.5)	435 (7⅓ min.)
41	59	305	18 (10.0)	465
41	57	320	16 (8.8)	465
41	56	335	15 (8.3)	465
40	55	355	15 (8.3)	545 (9 min.)
40	53	380	13 (7.2)	545
39	51	420	12 (6.6)	580
39	49	455	10 (5.5)	580
38	47	490	9 (5.0)	990 (16½ min.)
38	46	550	8 (4.4)	990
37	44	600	7 (3.9)	1300 (21⅔ min.)
37	43	660	6 (3.3)	
37	42	710	5 (2.7)	
37	41	770	4 (2.1)	
37	40	900	3 (1.5)	
37	39	1000	2 (1.0)	
37	38	1480	1 (.5)	
37	37	1900	0 (.0)	

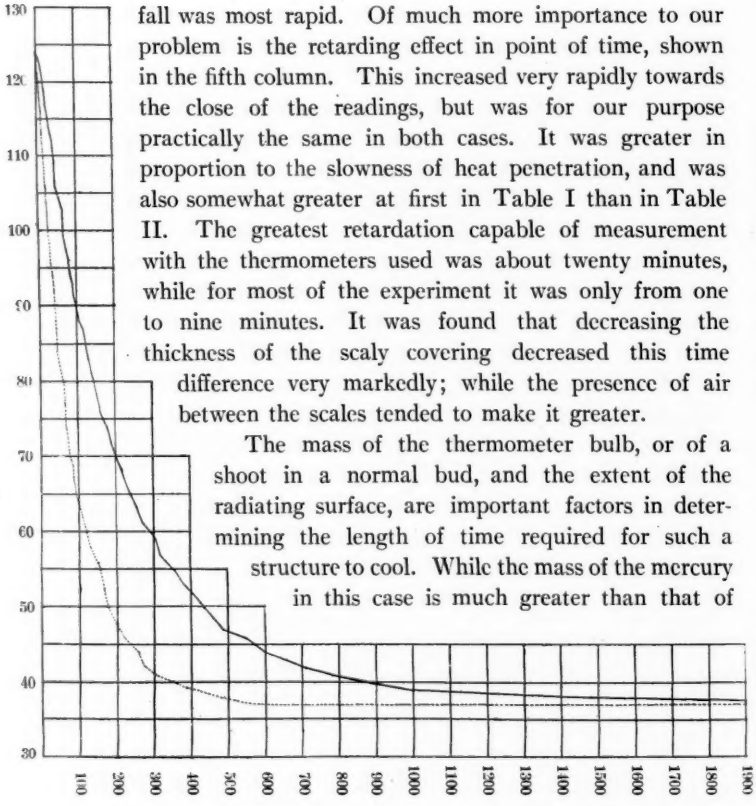

FIG. 8. ——— horsechestnut bulb; ..... naked bulb. Abscissas represent 5° F.; ordinates, 100 seconds. See Table III.

fall was most rapid. Of much more importance to our problem is the retarding effect in point of time, shown in the fifth column. This increased very rapidly towards the close of the readings, but was for our purpose practically the same in both cases. It was greater in proportion to the slowness of heat penetration, and was also somewhat greater at first in Table I than in Table II. The greatest retardation capable of measurement with the thermometers used was about twenty minutes, while for most of the experiment it was only from one to nine minutes. It was found that decreasing the thickness of the scaly covering decreased this time difference very markedly; while the presence of air between the scales tended to make it greater.

The mass of the thermometer bulb, or of a shoot in a normal bud, and the extent of the radiating surface, are important factors in determining the length of time required for such a structure to cool. While the mass of the mercury in this case is much greater than that of the shoot, its specific heat being only one-thirtieth that of water would render the two not very dissimilar, so far as the present problem is concerned. In apparent volume they do not differ greatly, so that the radiation surfaces of the two would be nearly the same.

I believe we are justified in saying that a normal horsechestnut bud would not behave in any essential way differently from the artificial one here used; and that the time for it to cool off would

be for all practical purposes not over about thirty minutes, no matter whether it was cooled very much or only a little, providing it was plunged directly into the cooler temperature.

We may also say, I believe, that smaller buds with thinner scales and smaller shoots will show a time period correspondingly less than thirty minutes, and a time difference which will approach more nearly zero. In the case of the willow buds with only one thin bud-scale, the time period and time difference must be very small indeed.

A number of readings were taken in which the thermometers were warmed up instead of cooled, and it was found, as expected, that the above generalizations applied in this case also. Providing that atmospheric changes out of doors are abrupt, I fail to see how the temperature at the center of a bud of medium size can be retarded more than five or ten minutes over practically all of the range of fall. A small bud would probably be retarded only about one to five minutes. Of course the retarding would be greater than this through the last degree and fraction of a degree, but this slight change, it seems to me, would be of little moment to the present question.

Buds in nature, however, are under slightly different conditions. Instead of being transported from one temperature to another, the temperature itself changes. We should therefore conduct some experiments in which the air itself is varied. This change is either very gradual, as when a thaw approaches, or more abrupt, as when the sun shines from behind a cloud upon the bulb, which is the only way in which abrupt changes are produced in nature. In either case they are much less violent than were our laboratory experiments. During warming by the sun, radiation from surrounding objects may play an important part and introduce still another factor. We should therefore conduct some experiments in which the air itself is warmed. The experiments with the horsechestnut bud already described in the discussion of the function of color are to the point here. They show in a surprising way that instead of retarding the rise in temperature within the bud, under these very natural conditions the bud-scales actually seem to hasten it.

These experiments were with direct sunlight. It seemed possible

that the readings might be different if radiated instead of direct heat was employed, especially since there is a considerable difference in the nature of such heat, as shown by the well-known fact that direct heat from the sun passes easily through glass into the greenhouse, but when radiated passes out with much greater difficulty, thereby warming the house.

A number of readings taken with naked and horsechestnut bulbs transferred from the shade to the surface of a black book in direct sunlight with the bulb raised 3–4^{mm}, or with the bulbs projecting several inches over the edge of the book which itself was raised several feet from the ground, or with the bulbs raised 7.5–10^{cm} above the surface of the book, showed no appreciable difference that could be referred to a difference in kind of radiated heat. There was some difference in the readings, of course, but this could be traced directly to the fact that there was more intense heat where the heat of radiation was also present. In case of more intense heat the extra absorbing power of the bud-scales was at first more obscured by the slightly greater retardation of heat-penetration due to the greater difference in outside and inside temperatures, as we should expect from the deductions from Tables III and IV. This was partially shown by the difference in locality of the crossing of the two curves plotted from each reading.

Looking at the matter from still another standpoint, we may consider how much time is required for a bud to thaw. As shown by the cover glass measurer, the wrinkled willow twigs thawed and became perfectly normal in thirty minutes at the temperature of the laboratory. Undoubtedly the ice had disappeared in about half the time. Large buds of horsechestnut will lose all their ice in about twenty-five minutes under similar conditions, and buds of Negundo in about fifteen minutes. The small buds of the black cherry require only about ten minutes for thawing. The time required in the laboratory for the various buds, therefore, is ten to thirty minutes. The question is whether when the temperature changes are slow the buds thaw proportionately more slowly. The answer must be that they will, slightly, just as a cake of ice will thaw more slowly when the temperature rises gradually than when the rise is abrupt. This difference is proportional to the size of the

ice cake, since it depends largely upon the non-conductivity of the ice and the greater quantity of heat required to convert ice into water. This heat is more slowly available when the change is gradual. Although no experiments were made under these conditions, it is to be expected, I think, that with long slow rise in atmospheric temperature, the retarding effect would almost if not quite disappear. Frozen peach buds, placed in the air at $-5.5°$ C., which gradually rose in 2 to 2.5 hours to a temperature of $-1.0°$ C., were completely thawed, apparently as soon at the temperature reached about $-2.3°$ C., thus following the general rule for frozen tissue.

We are now in position to consider the questions outlined on a previous page regarding the various ways in which the bud-scales may be supposed to act beneficially by modifying the temperature.

It was first suggested that they might retard the thawing out and thereby be of benefit to the bud. From the tables already given and the observations regarding them, it becomes at once apparent that the temperature modification which scales are capable of producing are, in the cases of moderate sized buds, of very little moment—not more than two or three minutes during most of the time, and then only when the change from one temperature to another is abrupt. When the transition is gradual, the retarding effect will be very slight indeed, and is frequently wholly offset by the absorbing power of the darker color. I cannot see how under any atmospheric condition the modifications can become great enough to be noticeable unless careful measurements are taken. The idea that a slow thawing is beneficial to plants has come about from analogy with the frosting of human tissue and from the consideration of the treatment which gardeners successfully give frosted plants. But the gardener's treatment consists in keeping the plant cool and dark for hours or even days after the freezing; while recent investigators have shown that slow or rapid thawing (*i. e.* conversion of the ice into water) in themselves bear no relation whatever to the extent of the injury. The gardener's treatment is essentially an after-treatment—while the plants are recovering from the shock. I have already cited the fact that buds of many trees, at least, may be thawed in an oven and then frozen alternately many times and still come out in the greenhouse apparently

as fresh as others not so treated.[17] The answer to this first question then, is, that bud-scales do not function by preventing rapid thawing of winter buds; neither does bark so function towards the twigs.

It has been suggested that bud-scales protect the bud by preventing rapid radiation from the delicate tissue during the cold nights, and thereby preventing a harmfully low fall of temperature. MÜLLER-THURGAU,[18] by placing one thermometer on some cotton under a 0.5^{sqm} cloth screen fastened 1^{dm} above the ground, and another thermometer outside, was able on a clear night to get 4° C. difference due to radiation. GRÜSS[19] states that differences in temperature due to radiation may be one or two degrees on cool nights just before sunrise, and as great a difference as 6° C. has been observed by other investigators. A difference of 4–6° C. would frequently be of importance to tender exotic buds in winter, but it is scarcely to be supposed that so slight a difference would be of much moment to the great majority of perfectly hardy species which withstand all of the fluctuations of our vigorous American climate without injury. Indeed these species seem capable of existing below any atmospheric temperature that has yet occurred in this country, as freezing mixture experiments have shown. Besides, the structure of buds does not lead one to expect a radiation screen as efficient as those specially constructed. Strictly speaking, the question here is not one of radiation of heat, since the scales are all more or less in contact, but of conduction, and as such has already been treated.

HENSLOW[20] has shown that it seems desirable for plants in temperate regions to protect their delicate bud-structures from loss of water when the bud is opening. Such loss he says is favored by radiation and heat absorption. The above objection will apply here also for the first part of this last statement, and the latter part is treated elsewhere in this paper.

[17] MOLISCH, H., Untersuchungen über das Erfrieren der Pflanzen. Jena. 1897

[18] MÜLLER-THURGAU, H., Ueber das Gefrieren und Erfrieren der Pflanzen. Landw. Jahrb. **15**:563. 1886.

[19] GRÜSS, Beiträge zur Biologie der Knospe. Pringsh. Jahrb. **23**:651. 1891–92.

[20] HENSLOW, G., On vernation and the method of development of foliage as protective against radiation. Jour. Linn. Soc. Bot. **21**:624. 1886.

In December 1901 some experiments were conducted to show whether twigs and buds while continuing frozen lost as much water by evaporation as when alternately thawed and frozen several times during the same period. It was found that they did not quite, and hence the question whether bud-scales may function by preventing too frequent thawing and freezing. Several buds of *Pinus Laricio* and horsechestnut, also several twigs 15^{cm} long of *Syringa vulgaris* and apple, were sealed at the cut end with Venice turpentine, weighed, and quickly placed on a tray in the open air. They were divided into two equal lots, and one of these was brought into the warmer laboratory for a few moments ten times, thus insuring ten alternate thawings and freezings. During the experiment, which lasted three days, the temperature ranged from $-18°$ C. to $-7°$ C. in the open. The results were as follows:

Horsechestnut buds continued frozen lost 0.4% of their water.
" " alternately thawed and frozen lost 0.6% of their water.
Pinus Laricio buds continued frozen lost 3.4% of their water.
" " " alternately thawed and frozen lost 5.0% of their water.
Syringa twigs continued frozen lost 1.3% of their water.
" " alternately thawed and frozen lost 2.4% of their water.
Apple twigs continued frozen lost 1.6% of their water.
" " alternately thawed and frozen lost 2.4% of their water.

In every case there was a greater loss of water from the buds which were alternately thawed and frozen. The difference was very marked, and in each case amounted to about one-third of the total loss. Considering the total quantity of water present, this was really a very slight increase in loss, however, being 0.25% in horsechestnut, 1.1% in lilac twigs, 0.8% in apple twigs, and 1.2% in pine buds; and with me it is a serious question whether, in all of these cases, so slight a difference would not be quickly equalized during spells of thawing by conduction from the older wood, if the twigs and buds were connected with the trunk in the normal manner. Again, the thawings in nature would probably be fewer, and it has not been shown that bud-scales prevent such thawings. It seems to me that here again a beneficial functioning of the bud-scales is very doubtful.

But the most vital argument against all these cases lies in the fact that experiments have shown that dark buds tend actually to

increase the heat absorption. Therefore, these considerations could scarcely have been instrumental in bringing about the existence of such structures.

The idea that bud-scales may protect the bud by warding off the hot rays of the sun applies mainly to the tropics. It seems to have been first advanced by TREUB,[21] who cites several cases, where in plants exposed to the hot tropical sun delicate young tissues were inclosed in enlarged stipular organs or else well-shaded by overlapping leaves or by other special structural provisions.

On the same subject, in 1891 another paper was published by POTTER.[22] According to this investigator many trees in the tropics protect their young leaves and shoots from direct sunlight by means of stipules. These organs were removed from a number of buds and in every case the leaves from these when mature were deformed and abnormal. The sunlight seemed to produce injury by causing more water to be evaporated than could be replaced. For this reason Artocarpus, the most pronounced type of this class, unlike most trees, produced leaves throughout the dry season, probably because of the stipular protection. Instead of by stipules some tropical plants obtain similar protection by various methods of leaf-folding, shading by older leaves, and coating with gum. Is there not inaccuracy here in his interpretation? Rather than by actually preventing the entrance of heat from the sun, which it seems such structures could do only to a slight extent, is it not more probable that they function simply by preventing the escape of extra moisture vaporized by the intense heat?

The relation of bud-scales to the young shoot when the bud is opening is discussed under internal moisture relations. Suffice it to say that the results reached seem to indicate that even in this case the scales do not function beneficially by modifying the heat.

It has sometimes been thought that the layers of hair and wool found in many buds, as for example in the horsechestnut, are for the purpose of modifying the heat conditions inside. To obtain

[21] TREUB, M., Iets over knopbedekking in de tropen. Hand. van. het eerste Nederlandsch Natuur- en Geneeskundig Congres. Amsterdam. 1887, p. 130. Ref. Bot. Centralb. **35**:328. 1888.

[22] POTTER, M. C., Observations on the protection of buds in the tropics. Jour. Linn. Soc. Bot. **28**:343. 1891.

evidence upon this point I performed the following experiment. The two thermometers used in the previous experiments were selected, and the bulb of one was coated with black cloth; that of the other was wrapped in a layer of cotton about twice the thickness of the wool in the horsechestnut bud, and was then coated with black cloth. The surface of both bulbs was therefore black.

TABLE IV.

Bulb covered with black cloth, and bulb covered with cotton and black cloth; transferred from a temperature of 56° C. to a room of 9° C.

Cloth bulb	Cotton bulb	Time	° Difference	Time difference
134° F.	134° F.	0 sec.	0° F. (0° C.)	0 sec.
130	131	5	1 (0.5)	7
128	131	10	3 (1.5)	10
125	128	15	3 (1.5)	15
123	128	20	5 (2.7)	15
222	127	25	5 (2.7)	15
119	125	30	6 (3.3)	20
117	123	35	6 (3.3)	20
114	121	45	7 (3.9)	20
111	119	50	8 (4.4)	25
109	117	55	8 (4.4)	26
106	115	60	9 (5.0)	30
104	112	70	8 (4.4)	30
100	110	80	10 (5.5)	37
98	107	85	9 (5.0)	40
96	105	95	9 (5.0)	40
93	103	105	10 (5.5)	40
91	101	113	10 (5.5)	42
89	99	120	10 (5.5)	45
87	97	130	10 (5.5)	45
86	96	135	10 (5.5)	43
84	93	145	9 (5.0)	50
82	91	155	9 (5.0)	55
80	89	165	9 (5.0)	55
78	88	173	10 (5.5)	62
77	86	178	9 (5.0)	72
76	85	185	9 (5.0)	75
74	84	195	10 (5.5)	75
73	83	205	10 (5.5)	80
72	82	210	10 (5.5)	85
71	81	215	10 (5.5)	95
70	79	225	9 (5.0)	95
69	78	235	9 (5.0)	100
68	77	250	9 (5.0)	105
67	76	260	9 (5.0)	110
66	74	270	8 (4.4)	110
65	73	285	8 (4.4)	120
64	72	295	8 (4.4)	130
63	71	310	8 (4.4)	135
63	70	320	7 (3.9)	135
62	69	335	7 (3.9)	140

TABLE IV.—*Continued.*

Cloth bulb	Cotton bulb	Time	° Difference	Time difference
61°F.	68°F.	355 sec.	7°F.(3.9C°)	155 sec.
61	68	370	6 (3.3)	155
61	66	380	5 (2.7)	155
60	65	405	5 (2.7)	145
59	64	425	5 (2.7)	160
58	63	445	5 (2.7)	185
57	65.5	475	5.5 (2.7)	210
56	61	510	5 (2.7)	270
56	60	550	4 (2.1)	310
55	59	585	4 (2.1)	545
54	58	630	4 (2.1)	545
54	57	685	3 (1.5)	545
53	57	745	4 (2.1)	1083
53	56	780	3 (1.5)	1083
53	55	895	2 (1.0)	1083
52	55	1015	3 (1.5)	1300
52	54	1175	2 (1.0)	1300
51	52.5	2155	1.5 (.8)	480
49	51	2635	2 (1.0)	1440
49	50	3355	1 (.5)	
48	49	4075	1 (.5)	

As expected, the retarding effect was apparent in this rather violent experiment, but it was not great. The maximum degree difference of 10° was less than one-half that produced by the bud-scales in Table III, while the time difference through the greater part of the experiment ranged from 0 to 4 minutes. I think it may be inferred that the wool in the horsechestnut bud retards the penetration of heat, when the changes are at all great, by 0.5–3 minutes. At any rate it seems evident to me that the retarding power of the wool in such buds as horsechestnut is insufficient to explain the presence of such a structure. This appears not only from experiment but from a general consideration of the thinness of such structures compared with the relatively great temperature differences which they are supposed to offer protection against, and must in order to be effective. Their true function, it seems to me, lies in an entirely different direction, as we shall see somewhat later.

In concluding this study of the relation of bud-scales to temperature the following summary may be made:

Bud-scales or bark cannot "keep out cold" during the cold spells of winter.

They seem not to modify the temperature sufficiently to be of

beneficial importance in preventing rapid changes, even if such changes are detrimental.

Rapid thawing in itself is probably not detrimental to buds and bark.

Bud-scales seem of no benefit in keeping out the heat from sudden bursts of sunshine. They do not appreciably prevent the loss of water by preventing alternate thawing and freezing. They do not retard radiation to any important degree.

Dark-colored bud-scales indeed, instead of preventing temperature changes actually seem to absorb more heat than if they were lighter colored.

"Wool" in buds does not function by modifying temperature changes.

Bud-scales do not seem to function in modifying temperature changes when the bud is opening.

Bud-scales may protect the delicate tissues in the tropics from heat, but it would seem rather from excessive transpiration due to great heat than from the heat itself.

Finally, we may conclude that as a factor in the evolution of buds and bark in cold climates temperature considerations have probably played a very minor part.

Internal moisture.

Of all the more important factors concerning the function of bud-scales, perhaps that relating to their inhibiting effect upon the loss of internal moisture is the least recognized by people in general. In scientific literature, however, it has received considerable attention. Most authors now consider this one of the principal functions of the bud-scales and also of the bark. The subject has been discussed briefly by CADURA[23] and GROOM,[24] but also more fully by GRÜSS,[25] who performed a number of experiments to demonstrate the point. His results may be summarized as follows. The first function of the scales consists in protecting the inner meristematic

[23] CADURA, R., Physiologische Anatomie der Knospendecken dicotyler Laubbäume. Breslau. pp. 42. 1887.

[24] GROOM, P., Bud protection in dicotyledons. Trans. Linn. Soc. II. **3**:255. 1893.

[25] GRÜSS, J., Beiträge zur Biologie der Knospen. Jahrb. Wiss. Bot. **23**:649. 1892.

tissue from loss of water. Even in summer and especially in fall, when the sap flow decreases, the tender embryonic interior of the bud must be protected from too great transpiration. Also in winter this function is not interrupted, for then the cold wind can bring into play its desiccating action. To prevent loss of water, cork layers are formed, or in place of these felty hairs may be produced. A third method consists in the excretion of resin. If, under constant temperature, the scales were removed from an oak bud, it soon died, even though there was a moderate amount of moisture present. The inner bud-scales dried out and perished, as well as the embryonic tissues. The young leaves of a beech bud so deprived of scales persisted much longer than did those of the European oak; which he thinks was because the former were hairy while the latter were not. Buds of horsechestnut proceeded to develop in spite of the removal of the scales, probably, he thinks, because of the thick wool among the young parts. Buds of *Abies pinsapo*, whose pitch had been removed by carbon bisulfid, dried out in a very short time. These experiments were all performed on twigs cut from the trees and placed in water.

In 1895 KNY[26] published a paper dealing with the transpiration and absorption of water by buds and twigs in winter. He cites WIESNER and PACHER as having shown that horsechestnut loses water from twigs in winter, and also HARTIG as having shown that many trees do the same. Experiments are given to show that in general not so much water is absorbed by these parts in saturated atmosphere as may be given off at an ordinary degree of saturation.

In 1895 some determinations of the amount of water lost by twigs with buds attached were made by the Cornell Experiment Station.[27] The experiments lasted three days, beginning April 7. The twigs were sealed at the cut end and kept in an open shed. The percentage of loss ranged from 2 to 10%, with an average of 5.4%.

In 1875 WIESNER and PACHER[28] found that twigs of horsechest-

[26] KNY, L., Ueber die Aufnahme tropfbarflüssigen Wassers durch winterlich-entlaubte Zweige von Holzgewächsen. Ber. Deutsch. Bot. Gesell. **13**:361. 1895.

[27] BAILEY, L. H., Cornell University Experiment Station Rep. **1896**:4.

[28] WIESNER u. PACHER, Ueber die Transpiration entlaubter Zweige und des Stammes der Rosskastanie. Oesterr. Bot. Zeitschr. No. 5. p. 9. 1875.

nut transpired an appreciable amount in winter at a temperature of 13–17° C. and a slight amount also at −10° C. This was true in older twigs. The leaf scars transpired more than the periderm. The winter buds also lost some water.

That there is actual loss of water in winter probably every one knows. My experiments given below show this very definitely, but perhaps few understand that there can be a loss when the tissue is frozen as well as when thawed, though less in extent. Water may evaporate to a large extent from ice crystals themselves, as is shown by the drying of frozen soil, damp clothing, and the frequent disappearance of small quantities of snow at temperature below the freezing point. In buds not all of the water becomes ice, and the remainder is free to evaporate as at a higher temperature.

The fall of temperature on the approach of winter is always accompanied by a decrease in the power of root absorption, and it has been shown that to a certain extent absorption is proportional to the temperature. In the case of our native plants, the decrease must be very considerable when the zero air temperatures have chilled the soil to a depth of many feet. A compensating decrease in transpiration must occur or otherwise the cells will suffer from too small water content. This is mainly accomplished by the fall of the leaves, but is greatly aided also by the coverings of the bud and the waterproof bark. But so far bud-scales would not be a necessity, because very little root absorption would probably be sufficient to supply the slight amount of water that could evaporate from unprotected buds, compared with that necessary to supply the leaves. Besides, it has been found that considerable water is present in the wood at all times, and in some trees even a larger amount than in the summer. The necessary factor, I suspect, lies in the decreased osmotic activity and vigor of the young tissue itself. During the summer the tendency to transpire is probably, a large share of the time, not so great as in the winter and spring because of the greater saturation of the air; but there are times during the summer when the transpiration is very great indeed. The young tissues do not then dry up very readily, so that little harm usually results. At this time I imagine the growing cells are osmotically very active and more easily draw to themselves

a supply of water sufficient to offset that lost in transpiration. In winter, however, the cells are inactive, and on account of the cold the osmotic force is much decreased, so that the cells find it impossible to resupply quickly the transpiration water when this function is very great.

That loss of water beyond a certain point is detrimental to the cell needs no further demonstration. It has been shown that each cell demands a certain percentage of water, depending mainly upon its activity and water content, in order to maintain its life-properties. If transpiration even for a short time reduces the water in the cells of the bud below the critical percentage, the cells will cease to remain alive.

During January 1901, I cut some twigs of horsechestnut, stripped off the bud-scales from some of the buds, and exposed the whole to an outside temperature of −18° C. to −12.3° C. for 24 hours, after which the twigs were placed with their cut ends in water in the greenhouse for further development. The buds all lived, although those without bud-scales were the first to commence growth. Subsequent experiments show that the reason why none died was because the exposure to the dry air was not long enough. On March 1 of the same year, buds of the black cherry, *Crataegus punctata*, horsechestnut, lilac, apple, and *Pinus Laricio* while still on the tree were deprived of their scales and each divided into two lots. One lot was left naked, the other was varnished completely with Venice turpentine to prevent loss of water. When the normal buds were opening May 8–10 it was found that both varnished and naked buds were all dead except on *Pinus Laricio*. On this plant the naked buds were all dead, but the varnished ones were alive, and later all developed into normal shoots.

The varnished buds in all cases seemed to be all sound and turgid until warm weather and time for swelling came, when they seemed to decay rapidly, and in no case except the pine did any swelling occur. I suspect that death here was due to the retardation of respiration owing to the lack of oxygen. The pine is normally closely surrounded by resin without a space inside as in horsechestnut, and possibly some other way is here provided for obtaining oxygen. The pine, therefore, is the only one of the series in which

the results of varnishing are important to us here. The naked buds of pine in every case began to dry and shrivel up after only a few days' exposure, and were quite dead long before the time for them to open. There seems no doubt whatever that the varnish preserved the pine buds by preventing loss of water. Without the varnish the pine was one of the first to succumb. That this thin layer of varnish replaced effectively the thick layer of scales is also good evidence toward the idea that the scales do not function by causing temperature modifications.

To determine just how much more water is lost from buds without scales the following experiment was performed. Several buds of *Pinus Laricio* and horsechestnut were separated from the trees by an incision at the base of the bud and the scales were removed from all. One-half were quickly varnished, weighed, and placed in the open air at −18° C., while the other half without varnish were weighed and exposed at once. Care was taken to seal up the cut end in both sets so that no water could escape that would not if the buds had remained on the trees. After three days at a temperature of −18° C. to −7° C. the results were as follows:

	Orig. weight	Final weight	Dry weight in oven	Per cent. H_2O lost in exp.
Pinus Laricio—continued frozen:				
With bud-scales	2.65gm	2.615gm	1.35gm	2.7
Without bud-scales	1.28	0.96	0.58	45.0
Aesculus hippocastanum—cont. frozen:				
With bud-scales	4.03	4.02	1.80	0.4
Without bud-scales	2.21	1.94	1.04	33.0
Same alternately thawed and frozen 10 times during experiment by bringing into the laboratory:				
With bud-scales	5.30	5.28	2.26	0.65
Without bud-scales	2.01	1.66	0.93	32.0
Syringa vulgaris—continued frozen:				
With bud-scales	1.15	1.135	0.52	2.8
Without bud-scales	0.41	0.32	0.18	39.0

I think that nothing could show better than these experiments the very great difference in amount of water transpired by buds protected by scales and those having none. No wonder that the loss of water oversteps the critical point and causes the destruction of the tissues.

The buds in the above experiment were separated from the tree upon which they grew, and therefore could not receive water from it to replace that transpired. It would be interesting to know how much water moves into the bud to replace the quantity lost, thus giving a better idea of the actual decrease in percentage within the cells. This has not been done for twigs at temperatures above freezing, but the following figures are available for the frozen buds of pine. I selected six vigorous buds of *Pinus Laricio*, all on the west side of the tree, deprived them of their bud-scales and allowed them to remain exposed three days. The temperature during this time ranged from −18° C. to −6.7° C., so that the twigs as well as the buds were constantly frozen. Three of the buds were cut off, the cut surface sealed, and placed in a tray at the base of the tree, while the other three remained attached. The results were as follows:

	Wt. at end of exp.	Dry weight	Difference	Per cent. H_2O present at end of exp.	
Cut buds—					
No. 1	0.105gm	0.061gm	0.044	41.9	
" 2	0.150	0.090	0.060	40.0	41.2 average
" 3	0.230	0.134	0.096	41.8	
Not cut—					
No. 1	0.255	0.139	0.116	45.5	
" 2	0.240	0.121	0.119	49.5	47.5 average
" 3	0.210	0.110	0.100	47.6	

It seems, therefore, that there was a rise of about 5% of water into the bud while the tissues were frozen. This is quite possible, since only a portion of the water was converted into ice, the remainder remaining fluid in the walls and protoplasm and still capable of movement. The figures given above for the loss of water from desquamated buds are therefore slightly too large in every case. It may be noticed by computing corresponding figures that the loss of water during this last experiment is slightly less than in the two previous experiments in which desquamated buds of *Pinus Laricio* were used. This was due to the fact that the last experiment was conducted in a different place, on the other side of the building. I have found that exposure makes a very considerable difference in the loss of water, and readings which are to be compared must

be taken in the same place under the same weather conditions. The rise of 5 per cent. is only a small part of the whole water lost. How much will rise into the bud when the tissues remain thawed was not determined.

The question arises whether the damage to the bud is done while the latter is frozen or thawed. I believe that injury is done both while thawed and while frozen, for the reason that the loss of water from unprotected buds is sufficiently great to cause death at either time. However, probably more damage is done above freezing point, because here the loss must increase with the temperature much faster than does the conduction of water in the bud.

The evidence therefore seems to be sufficient to warrant the conclusion that the loss of water during the winter is a danger against which the bud-scales and bark serve as protective organs. Next to the warding off of mechanical injury this is probably their most important function.

Protection of the young shoot.

In many trees, notably in maples, horsechestnuts, oaks, etc., the growth of the young shoot is accompanied by a growth in length of the bud-scales, especially of the inner ones, so that a sort of telescopic tube is formed in which the young shoot remains concealed, frequently until a growth of 2–8^{cm} has taken place. The function performed by the bud-scales at this time has long been a subject of interest to investigators, among whom GRÜSS[29] has given us the most comprehensive account.

According to GRÜSS, the protection lies in the ability of the scales to prevent the penetration of extreme cold on freezing, or great heat when thawing out. The greatest danger to buds from cold, he says, is in the spring after activity has commenced, when a few degrees of frost will often kill the tissue. It is on just such occasions that the frost is likely to be of short duration, and to occur for a few hours only, just before sunrise. It is quite conceivable that the non-conductivity of the scales would be sufficiently great to prevent an extreme fall of temperature within the bud during that short time. Again, if the cold was severe enough actually to freeze

[29] GRÜSS, J., Beiträge zur Biologie der Knospen. Jahrb. Wiss. Bot. **23**: 649. 1892. See also HENSLOW, *l. c.*

the tissues, then when the sunlight fell upon the buds in the morning the scales would prevent injury from too rapid thawing. To support this view he found that shoots of *Picea Engelmanni* deprived of scale-caps perished, while normal ones did not. Shoots of *Betula alba* projecting slightly beyond the sheath were overtaken by a slight frost. The portion beyond the sheath was killed while the protected portion was uninjured. At a temperature of −3° R. the portion of the shoot outside of the sheath in Larix and *Pinus Cembra* was completely killed. A horsechestnut tree at −5° R. had the portion of shoot projecting beyond the scales killed, the rest was uninjured. At −5° R. shoots of this species were killed, while at −4° R. they were all right. Buds of *Acer platanoides* still in the scales were killed at −4° R. Populus cannot stand a cold of −5° R. after breaking out of the buds. Shoots of birch not inclosed were killed at −5° R., but not at −4° R; those still in the bud-scales were uninjured at −5° R.

I am unable to agree with GRÜSS that these cases of protection are due mainly to the modification of the temperature. During the spring of 1902 I removed the scales from a large number of oak buds, also from birch and from maple. This was done about the time that the buds were swelling rapidly; but no frosts occurred afterward until the leaves were quite far developed. Many of the oak buds so treated died, and the rest were retarded or deformed in various degrees. The appearance in all cases was that of drying out—as though the tissue had simply shriveled up from lack of water. The birch and maple showed the same effect though in a less degree. Any one seeing these experiments could scarcely believe otherwise than that the loss of water caused the injury. When the shoot is young the epidermal cells are but slightly cutinized, and are therefore much more pervious to water vapor than after having become more mature. At this period also the cells have probably not yet reached their full osmotic activity, and are still unable to replace rapidly the lost water. It is not surprising, therefore, that shoots should be injured at this period. Even in tropical regions, young tissue is protected against transpiration by being folded within the leaves, or in other ways. GROOM[30] has brought this point out nicely

[30] GROOM, P., Bud protection in dicotyledons. Trans. Linn. Soc. II. **3**: 255. 1893.

for temperate regions. He points out that old parts often cover the new. The blade of the young leaf is often covered by stipules. The most critical time is when first exposed, the walls then being thin and feebly cutinized, the chlorophyll dilute and easily decomposed. The blades after coming out are folded and covered with hair in such a way as to diminish transpiration and radiation as well as to reflect light. According to GROOM the function of mucilage and tannin in buds is to help hold the water in the young shoots.

In this light I think we can see the function of the air and wool which gave the negative results in the temperature experiments. Water vapor diffuses through air quite slowly unless the air itself is in motion. If a layer of substance containing air passages such as wool, through which there is almost no circulation, is placed around a damp object, the evaporation from the object is very much retarded because the air in contact with the water is almost saturated under certain conditions.

The horsechestnut wool, therefore, although not functioning in the bud would become a most efficient protection against loss of water from young shoots after leaving the bud-scales. I think this is the purpose of nearly all hairy coverings of young flowers and branches, which view is strengthened by the fact that in most cases the hair disappears before maturity. The putting up of the hair already in the bud insures its presence at the very earliest moment when it shall be required. These and other similar observations have quite firmly convinced me that the growing out of bud-scales and the presence of hair on the young organs is mainly for the purpose of retarding transpiration. In some cases they may be important also for mechanical support.

The observations of GRÜSS in regard to death at temperatures slightly below the freezing point I think can be explained in this way. When tissues freeze the water enters the intercellular spaces and can from there escape more easily to the outer air. If, however, hair or scales were present, not so much water would escape while the tissue was frozen, and a lower temperature might be necessary to cause fatal loss of water. In the case where $-5°$ R. caused death while $-4°$ R. did not, it is possible that freezing just began at that point which is near the over-cooling point of such tissue. It may

be, however, that there are times when the temperature barely falls to the death point, and then only for a very short time just before sunrise, when the bud-scales may save the life of the bud by preventing a temperature fall of from 0.5° to 1° for a very short time, and this little we must admit they are capable of doing. But we must consider that the period when the young shoot is covered by the extending scales, in America at least, lasts only about three or four days at the most, while the probability of a fall just to the critical temperature during this short period is indeed very slight. There may be no frost at all or there may be a very severe one. Only in the case of such a slight frost just reaching the critical temperature could the scales be of benefit, and even this injury would not be fatal to the tree, since another crop of accessory buds can grow out in a short time. The chance to function is therefore very slight, and the effect could not compare in importance to the plant with the benefits obtained according to the above theory, because in the absence of scales nearly all buds of whatever crop would run great danger of being killed by loss of water. It is not reasonable to suppose, therefore, that the benefit derived by modifying temperature is sufficient to have played any great part in causing natural selection to evolve such an elaborate structure for this purpose.

Relation of bud-scales to mechanical injury of the bud.

The idea that the bud-scales serve to protect the delicate young tissues within from mechanical injury is of course not new.[31] In fact, probably everyone feels that this must be, if not the most important function, at least a prominent factor in the work of protection. Nevertheless the subject seems to have received little attention in physiological works.

The young shoots of our definite-growing trees as they exist through the winter are very tender organs, composed mainly of thin-walled parenchyma. In most cases the epidermis is still thin, no fibrous or other supporting tissue has been developed, and the vascular bundles contain only spiral vessels, the result being that they are very brittle and capable of resisting only the slightest concussions. The effect of these abrasions is besides very much inten-

[31] GROOM, P., Bud protection in dicotyledons. Trans. Linn. Soc. II. **3**:255. 1893.

sified by the comparative rigidity of the twig to which the buds are attached. Danger to buds from mechanical causes during the winter may be classified under three heads: danger from birds, from passing objects, and from wind.

Birds.—Young and tender plant tissue is a favorite food for some birds, as for instance the purple finch.[32] It is quite possible that if the bud-scales were absent from our native trees, many species of birds would take advantage of this easy method of obtaining food, at a time when food is scarce. More birds might remain in the North than now, so that altogether it seems probable that trees would suffer severely, if they were not actually killed, by the depredations. A firm hard armor is therefore desirable.

Passing objects.—During my experiments with buds from which the scales had been removed to determine the effect of evaporation, etc., many buds were prepared in a thicket of lilac bushes about six feet high. I found great difficulty in passing through to inspect the buds without breaking off some of them. A moment's absent-mindedness while taking notes would frequently result in the destruction of several buds, a very slight touch only being necessary to dislodge the tender shoot, and the brittleness was of course very much increased when the tissues were frozen. If the above results occurred when care was observed in passing, how much greater would be the damage caused by animals both large and small running thorugh the dense copses in winter. Protective armor seems here again to be a necessity.

Wind.—In our American climate, at least, this is much stronger in winter than in summer—in other words, at exactly the time when buds are frozen and therefore most brittle. The beating together of branches during a heavy wind storm could scarcely fail to do incalculable damage to a tree with unprotected buds. SCHUMANN[33] believed that one of the most, if not the most, important functions of bud-scales is to resist injury from heavy winds. I myself was

[32] FORBUSH, E. H., Birds and woodlands. Mass. State Board of Agric. Rep. **1900**:300. BEAL, F. E. L., How birds affect the orchard. Year Book Dept. of Agric. **1900**:291. ALTUM, Zerstörung von Baum- besonders Fichten- und Kiefernknospen durch Vögel. Zeitschr. Forst. u. Jagdu. **29**:224–230. 1897.

[33] SCHUMANN, C. R. G., Anatomische Studien über die Knospenschuppen von Coniferen und dicotylen Holzgewächsen. Biblioth. Botan. 15:23. Cassel. 1889.

much impressed by the abrasive power of objects beaten about by the wind in winter in the case of firm paper tags attached by strings two inches long to twigs of apricot. During the winter they succeeded not only in marring the bark, but also in completely disintegrating all the buds within reach by simple contact while being blown about. It would seem that the beating together of larger and harder objects like the branches themselves would do even more damage. Therefore, in this case also a firm outer coat is demanded.

I believe that we are justified in concluding from these considerations that mechanical protection is one of the most important functions of the bud-scales—indeed the most important of all.

Some other suggested functions of bud-scales.

GRÜSS[34] included the storing of food material as one of the functions of bud-scales. Bud-scales undoubtedly do store considerable food in some cases, but this is a secondary rather than a primary function. We can scarcely consider this as having been an important factor in the evolution of the scales.

GROOM[35] suggests injury from excess of light as one of the things from which bud-scales protect the delicate young tissue; that when about to unfold the cell walls are thin and the chlorophyll is dilute and easily decomposed. If we conclude that the red color in young plants is for the purpose of modifying the light, then perhaps there is some danger to the young tissues of the bud from too strong light, since these usually become red. No direct evidence however is at hand to warrant this conclusion, and since such protection could be obtained with the expenditure of less energy by the use of hairs or bloom, there seems to be little reason for considering this a determining function of the bud-scales.

One of the most interesting suggestions is that of CADURA[36] to the effect that in addition to protecting the delicate parts from loss of water, great radiation, cold, and too great gas interchange,

[34] GRÜSS, J., Beiträge zur Biologie der Knospen. Jahrb. Wiss. Bot. **23**:648. 1892.

[35] GROOM, P., Bud protection in dicotyledons. Trans. Linn. Soc. II. **3**:255. 1893.

[36] CADURA, R., Physiologische Anatomie der Knospendecken dicotyler Laubbäume. Breslau, pp. 42. 1887.

bud-scales function beneficially by mechanically preventing too early opening of the buds. That buds, as for instance the horse-chestnut and lilac, do open several days earlier when deprived of their scales I have frequently noted in connection with the experiments conducted on desquamated buds in the greenhouse. Still the evidence is not sufficiently strong to warrant the assumption that this is an important and determining function of the scales. Scaleless buds in nature instead of opening very early open quite late, and, as SCHUMANN[37] has insisted, many buds during warm wet autumns open in spite of the scales. My own observations would tend to show that at best they can retard the opening not more than three or four days.

SUMMARY.

Buds containing a considerable number of well differentiated organs are usually protected by scales. Those sunk in the bark usually contain little besides the growing point or rudimentary leaves. Bud-scales are not only the most feasible structures for covering a large bud, but they also allow the bud to swell, and protect the young shoot when unfolding.

The bud fundament in most trees is laid down early in the summer, grows gradually till late autumn, remains dormant until early spring, then passes through a period of swelling preparatory to unfolding.

Dark-colored buds are usually warmer within than light-colored ones; but the question whether there is any relation between dark color and the early opening of the buds was not decided.

Ice may be found in most buds when the temperature has fallen as low as −18° C. and usually in large quantities. Its absence in other cases is due to small-celled tissues and meager water content.

Frozen twigs are smaller than normal ones. Their contraction occurs mainly in the bark.

Frozen buds do not show this contraction so plainly, probably because of change of form in the bud-scales.

The thawing of buds, if sufficiently slow, is per degree in inverse

[37] SCHUMANN, C. R. G., Anatomische Studien über die Knospenschuppen von Coniferen und dicotylen Holzgewächsen. Biblioth. Botan. 15:27. 1889.

ratio to the freezing, so that at the freezing point of the tissue all the ice will have disappeared.

Regarding the function of bud-scales, there is little evidence that they function by keeping the water out; neither are they important to the plant as modifiers of temperature.

Bud-scales have probably been evolved to prevent excessive transpiration and to protect the delicate tissue from mechanical injury.

When the bud opens the scales often grow out, forming a tube-like structure which protects the young shoot from too great loss of water.

The wool in such buds as horsechestnut is not to modify the temperature, but to protect the young shoot from too great transpiration.

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THE LIFE HISTORY OF POLYSIPHONIA VIOLACEA.

CONTRIBUTIONS FROM THE HULL BOTANICAL LABORATORY. LXXXIII.

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THIS preliminary paper will give a brief sketch of my cytological studies on *Polysiphonia violacea* Grev., which were begun last summer at the Marine Biological Laboratory, Woods Hole, Mass., where I occupied a Carnegie Research Table, and were continued at the Hull Botanical Laboratory as a Fellow in the University of Chicago. The problem was suggested by Dr. BRADLEY M. DAVIS, to whom I wish to acknowledge my great indebtedness for his assistance and criticism during the progress of the investigation.

Many points, which for the sake of brevity are omitted in this paper, together with a discussion of literature will be presented in a detailed account with plates to be published later.

METHODS.

The material was killed and fixed in Flemming's fluids, in several modifications which contained the osmic acid in various proportion, Hermann's fluid, 1 per cent. picric acid, and others; among which the weaker formulae of Flemming proved most effective. The best fixation for the study of spermatogenesis and the germination of carpospores and tetraspores was obtained in material killed in weak chrom-acetic acid (Flemming's formula), without any osmic, as follows: 1 per cent. chromic acid, 25^{cc}; 1 per cent. glacial acetic acid, 10^{cc}; sea water, 65^{cc}.

Material was left in the fixing fluid five to forty minutes, and then washed in a gentle stream of sea water. If material remains for a longer time in chrom-acetic acid it becomes very soft and breaks apart. The washed material was passed very gradually through a series of alcohols beginning with 30 per cent., and imbedded in 52° paraffin. The sections were cut 3–5 μ in thickness and stained with safranin-gentian-violet or with iron-alum-haematoxylin, sometimes followed by some plasma stains as orange G, Bordeaux red, Congo

red, or safranin. Preparations were studied with a Zeiss apochromatic immersion 1.5^{mm}, N. A. 1.30, and compensating oculars.

GERMINATION OF THE CARPOSPORE AND TETRASPORE.

It is very easy to obtain the early stages in the germination of carpospores and tetraspores. Fruiting plants, placed in a dish of sea water over night, will discharge great quantities of spores. These fall to the bottom of the dish and germinate at once. The germinating spores may be readily gathered from the bottom at the proper hours to obtain critical stages.

The first division of the carpospores and tetraspores takes place within 10–15 hours after their escape from the parent plants.

The cytoplasm before the first division shows a coarse network or very irregular alveolar structure on the periphery, which becomes much finer around the nucleus. The nucleus has a very delicate membrane, within which lies the linin network, much finer in structure than that of the cytoplasm. The delicate transverse walls of the alveoli of the cytoplasm seem to end on the nuclear membrane where the linin thread starts, which leads the writer to believe that there is some relation between the positions of the walls of the cytoplasmic alveoli and the linin of the nuclear network. The nucleus contains one or two nucleoli homogeneous in structure.

Approaching the prophase of mitosis the linin threads become more and more conspicuous and chromatin granules appear in rows; but without constructing a uniform continuous spirem the threads segment into a number of chromosomes. The nucleus becomes surrounded by dense kinoplasm consisting of very minute closely crowded granules, and the outer margin of this kinoplasmic mass assumes a fibrillar structure which finally ends in the alveoli of the cytoplasm. The distinct concentration of the kinoplasmic masses at the poles to become the centers of the dynamic activities of the mitosis does not occur until the chromosomes are arranged in an equatorial plate. The nuclear membrane persists through the prophase, which makes it evident that the spindle is entirely intranuclear in origin.

The chromosomes at the equatorial plate split longitudinally, and the two groups of daughter chromosomes pass to the opposite poles of the spindle, where they become closely crowded in a mass near the center of the accumulation of kinoplasm.

The nucleoli sometimes fragment into two or three small globules, or decrease in size without fragmentation, finally vanishing during the late prophase. New nucleoli appear after the formation of the daughter nuclei. No such close relation seems to exist between the linin thread and the nucleolus as to warrant a belief that in Polysiphonia the nucleolar substance passes directly into the linin thread to form the chromosomes, as is reported in Nemalion.

No centrosomes could be found during this process of mitosis, although the kinoplasm surrounding the nuclear membrane becomes denser during later prophase and finally accumulates at the poles of the spindle at the time of the metaphase. The masses of kinoplasm present no radiations, yet it seems probable that they function as centers of dynamic activity during mitosis, persisting until the daughter nuclei are organized.

The mitoses within the germinating carpospore and tetraspore correspond in all essentials, except that it became at once apparent in the investigation that the nucleus of the carpospore contained about twice as many chromosomes as that of the tetraspore. Counts of the chromosomes made during the later prophase and metaphase of the mitosis made it clear that the nucleus of the carpospore contains about 40 chromosomes and that of the tetraspore 20.

SPERMATOGENESIS.

The mitoses in the vegetative cell of male or antheridial plants will be described before those of spermatogenesis. During the prophase the chromatin granules increase in size and become grouped as a number of short rod-shaped bodies upon the linin thread, without developing a regular and uniform chromatin spirem. The linin thread then segments into 20 chromosomes.

Polysiphonia, as a rule, is dioecious; however, cystocarpic plants sometimes produce antheridia, a condition which will be described later with other abnormalities. The antheridia develop as lateral branches near the tips of the main filaments. Each branch consists of a central axis from which clusters of sperm mother-cells or spermatocysts arise at the side on short stalk cells.

The cytoplasm of the spermatocyst has a delicate granular structure and contains a large vacuole, generally in the center of the cell. Its nucleus in the resting state is similar to that of the vegetative cell,

and during prophase the linin network becomes more conspicuous and finally segments into 20 chromosomes. The kinoplasm around this nucleus is rather scanty, even after the spindle fibers are formed. The spindles are intranuclear. No centrosome could be found, but there is a concentration of kinoplasm at the two poles.

After anaphase, the nuclear membrane dissolves and the vacuole intrudes into the nuclear cavity between the two sets of daughter chromosomes, one set passing to the apex and the other remaining at the base of the sperm mother-cell. The upper part of the cell, including the vacuole, is then cut off as the sperm from the lower portion by a cleavage furrow, which crosses the cell somewhat obliquely.

The nucleus which remains at the bottom of the sperm mother-cell now repeats this mitosis, forming a second sperm, and perhaps two or three more are developed before the antheridium ends its fertility.

OOGENESIS AND FERTILIZATION.

The mitoses in the vegetative cells of the female or cystocarpic plant are similar to those of the male. The number of chromosomes is invariably 20.

The female organ or procarp develops from a central axial cell, next to the apical cell of a short lateral branch. The central axial cell gives rise to a pericentral cell from which by successive mitoses a four-celled carpogonial branch is formed. The terminal cell of this series becomes the carpogonium, situated as a rule above the pericentral cell, owing to the curved growth of the carpogonial branch.

The carpogonium is at first round and the nucleus lies in its center. While this nucleus undergoes a typical mitosis to form two nuclei, the carpogonium puts forth the process which is to become the trichogyne. After mitosis one of the nuclei proceeds into the developing trichogyne to become a trichogyne nucleus, and the other remains below in the carpogonium as the gamete nucleus.

Coincident with the development of the trichogyne, the pericentral cell gives rise to the two sets of auxiliary cells, one of which is a series of three or four, formed above, so that they lie just beneath the carpogonium, and the other series consists of two cells formed below.

When the sperm comes in contact with the trichogyne, the walls

between dissolve, the contents of the sperm cell enter the cytoplasm of the trichogyne, and the sperm nucleus passes down into the carpogonium where the fusion of the male and female nuclei takes place.

The trichogyne nucleus may be found even after the sperm nucleus has passed into the carpogonium. But later, when the trichogyne becomes separated from the carpogonium, its nucleus can scarcely be distinguished. The trichogyne then shrivels and dies.

The carpogonium after fertilization unites with one of the auxiliary branch cells which lies beneath, and the latter also fuses with the pericentral cell, thus providing a passage into the pericentral cell for the fusion nucleus of the fertilized carpogonium. Then the remainder of the auxiliary branch cells fuse with one another and with the pericentral cell, which results in a large fusion cell, the central cell, that naturally contains a number of nuclei.

The nuclei in the central cell are of two sorts with respect to origin: first, there is the fusion nucleus from the carpogonium (sporophytic); and second, there are a number of nuclei derived from the auxiliary cells, which are of course gametophytic. The fusion nucleus gives rise to a series of nuclei by typical mitoses which present 40 chromosomes as a sporophyte number. The central cell now develops several lobes into which these sporophytic nuclei pass. Further mitoses increase this number, and each lobe then cuts off a carpospore terminally, which is attached to the central cell by a short stalk.

After the carpospores are formed, the central cell increases in size greatly, absorbing the stalk cells, and even the central axial cell also becomes involved in this general cell fusion. These very extensive cell unions are probably concerned with the nourishment of the carpospores.

Some of the gametophytic nuclei derived from the auxiliary cells remain in the central cell, increasing in size and finally breaking down after a number of peculiar changes. Others of the gametophytic nuclei divide amitotically to form the paranematal filaments which lie under the wall of the cystocarp.

TETRASPORE FORMATION.

The tetrasporic plant normally never produces antheridia or procarps, and the cytological studies on the vegetative cells give proof that it differs in an important respect from the sexual plants. The

mitoses in growing regions of the tetrasporic plant show that the nuclei have 40 chromosomes (the sporophyte number), while it will be remembered that the nuclei of the sexual plants have 20.

I shall not enter at this time into a detailed description of the events which take place during the formation of the tetraspore mother-cell; the only thing to be remembered is that the number of the chromosomes appearing during this mitosis is 40, so that it follows that the nucleus of the tetraspore mother-cell contains 40 chromosomes.

The nucleus of the tetraspore mother-cell increases somewhat in size, accompanied by the growth of the cell itself; yet the latter is relatively slow until just before the first mitosis of the nucleus, but very rapid after that.

The resting nucleus of the tetraspore mother-cell contains a fine network of linin in which the chromatin is distributed irregularly in larger and smaller granules. The nucleolus has no visible connection with the linin thread. With the further growth of the nucleus the linin thread increases in thickness; in such an irregular way, however, that in some parts the threads are uniform in thickness and in the others they appear to have knots. The chromatin thread now forms a fairly well-developed spirem.

This condition presently passes into the so-called stage of synapsis, when the spirem consists visibly of two parallel threads close together, while in the other parts the two are in contact side by side or fused into a single thread. The two threads may represent, according to recent interpretations of synapsis, chromatin of maternal and paternal origin.

After synapsis, the tangled thread becomes distributed throughout the cavity of the nucleus. The spirem now shows the longitudinal fission which precedes the separation of chromatin granules into two sets, and then the spirem segments into 20 chromosomes, each showing clearly its bivalent nature.

While this process of chromosome formation is going on in the interior of the nucleus, the kinoplasmic material surrounding the nucleus becomes concentrated at two poles of a spindle, and when the chromosomes are arranged in the equatorial plate a minute body occupies the center of each pole. The body might be called a centrosome, but it has not been possible to recognize its presence during prophase or to follow it after anaphase.

It is interesting to note that the two poles are not in a straight line perpendicular to the center of the equatorial plate, but are asymmetrical and less than 180° apart. Each of the 40 sporophytic chromosomes composing the 20 pairs (bivalent chromosomes) arranged in the equatorial plate now splits longitudinally, so that a large number of univalent chromosomes results, probably 80 in all, although I was unable to count the exact number.

The group of 80 grand-daughter chromosomes separates into two sets, but resting neuclei are not formed, and their further distribution by the second mitosis begins at once. The axes of the two spindles of the second mitosis lie perpendicular to each other, and their complex relation to that of the first will be described in the final paper. Kinoplasmic masses occupy the poles of the spindles in the second mitosis, and each contains a centrosome-like granule.

Now, each group of 40 chromosomes, following this first mitosis, separates into two sets of grand-daughter chromosomes, 20 in each set, which are attracted toward the respective poles of the two spindles, where the kinoplasmic material becomes more pronounced than before. These chromosomes, after reaching the four poles, become massed together, lose their individual outlines, and larger and smaller granules appear shortly after on linin threads which later become contained in the four daughter nulcei.

It is a remarkable fact that the membrane of the original nucleus in the tetraspore mother-cell persists through the two mitoses which have just been described. The area included by this membrane increases in size with the growth of the cell. The cytoplasm around it shows larger alveoli, which become smaller in the vicinity of the original nuclear membrane, and at last passes into the kinoplasmic fibrils immediately surrounding it.

At this time constrictions appear simultaneously in the area marked by the original nuclear membrane. The kinoplasm intrudes into this area in a very interesting manner, which cannot easily be described without figures, but results in the organization of the four daughter nuclei that are to be contained in the tetraspores.

The division of the tetraspore mother-cell does not take place simultaneously with the events described above. Cleavage furrows start along four lines on the periphery of the cell, a little before the end of the nuclear division, and proceed more rapidly after its com-

pletion. During the entire process of the tetraspore formation, the mother-cell is connected by a strand of protoplasm with the stalk-cell, and probably gets much nourishment through this strand, for the tetraspore mother-cell increases greatly in size. Finally, the cleavage furrows meet in the center between the four daughter nuclei, thus dividing the protoplasm into four tetraspores.

ABNORMALITIES.

Normally, the male and female organs and the tetraspore are never developed in the same plant, but it often happens that the male and female organs are produced on the same individual, and occasionally antheridia are formed on the same branch with procarps and cystocarps. The sexual cells in these cases are developed normally, the number of the chromosomes being always 20. Cystocarpic plants have also been found producing cells whose lineage is identical with that of the tetraspore mother-cell. However, I have never seen evidence of nuclear division in such a cell; cleavage furrows appear and cut deeply into the protoplasm, which nevertheless remains undivided, so that tetraspores are not formed. Whether this cell may escape and germinate as a monospore has not yet been determined.

CONCLUSION.

The nuclear conditions in the life history of Polysiphonia may be summarised as follows:

1. The germinating carpospore contains 40 chromosomes, and the tetrasporic plant the same number; so it may be inferred that the tetrasporic plants come from carpospores.

2. The germinating tetraspore contains 20 chromosomes, and the sexual plants (gametophytes) the same number; so it may be inferred that the sexual plants come from tetraspores.

3. The nuclei of the gametes (sperm and carpogonium) contain each 20 chromosomes. The fusion nucleus (sporophytic) in the fertilized carpogonium presents 40 chromosomes, and gives rise to a series of nuclei. Some of these enter the carpospores, which are consequently a part of the sporophytic phase to be continued in the tetrasporic plant. The gametophytic nuclei in the central cell of the cystocarp (with 20 chromosomes) either break down or form the paranematal filaments.

4. Tetraspore formation terminates the sporophytic phase with typical reduction phenomena, so that the tetraspores are prepared to develop the gametophytic generation.

5. There is thus an alternation of sexual plants (gametophytes) with tetrasporic plants (sporophytes) in the life history of Polysiphonia, and the cystocarp forms a part of the sporophytic phase.

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THE STRUCTURE AND DEVELOPMENT OF THE BARK IN THE SASSAFRAS.

HOWARD FREDERICK WEISS.

(WITH NINE FIGURES)

THE common sassafras occupies a somewhat isolated position among northern trees. It is not only the single living representative of the genus Sassafras, but it belongs to the Lauraceae, a family with many arboreal genera in tropical and subtropical regions, but with very few in the cooler parts of the earth. The tree is further remarkable because its young branches remain green for a considerable period, differing in this respect from the majority of the trees among which it grows. For these various reasons it was hoped that a study of the bark might reveal features of interest.

MÖLLER has already studied the bark in several genera of the Lauraceae and has included in his published account a short description of what he found in the sassafras.[1] According to his researches the family as a whole is characterized by the following peculiarities in the bark: a late appearance of cork; an epidermal origin of the phellogen; a slight development of collenchyma in the outer cortex, most of the cells remaining thin-walled and parenchymatous; the occurrence of stone-cells in the medullary rays between the strands of primary sclerenchyma; the presence of ethereal oil and slime in some of the parenchyma cells; the scattered bast fibers in the inner or secondary bark. With regard to the sassafras in particular he notes that the cork is homogeneous and composed of thin-walled cells and that the inner bark is destitute of stone cells. It should be remarked that most of MÖLLER'S material in this family consisted of dried bark, much of which was fragmentary and in poor condition.

In his more general account of the Lauraceae SOLEREDER accepts the majority of MÖLLER'S statements with regard to the bark.[2] Quoting from J. E. WEISS, however, he notes the fact that the phellogen is not invariably epidermal in origin, but that it is sometimes derived

[1] Anat. der Baumrinden 103–110. 1882.

[2] Syst. Anat. der Dicot. 795. 1899.

from the layer of parenchyma just within the epidermis. He also remarks that the secondary bast fibers, although usually scattered, form distinct strands in certain genera, and that the individual fibers are normally four-sided in cross section with narrow lumina.

The present investigation is based on material collected near New Haven, Connecticut, and is confined to the stem and its branches, no reference being made to the bark of the root. The tissues described may be classified as follows:

PRIMARY TISSUES	SECONDARY TISSUES
Epidermis	Tissues derived from the cambium ring
Outer cortex	The phellogen and its derivatives
Primary medullary rays	
Primary bast	

PRIMARY TISSUES.

Epidermis.

The epidermal cells are characterized by a strongly thickened cuticle. Close to the growing point they are isodiametric and thin-walled, but the cuticle begins to make its appearance very early and

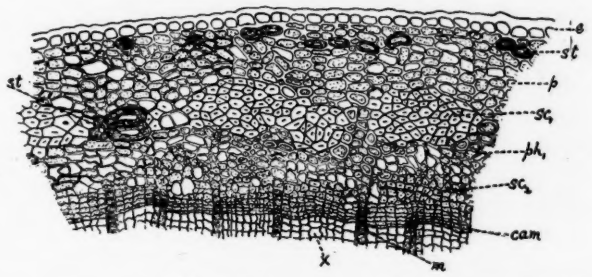


FIG. 1.—Cross-section through bark one year old. ×70. *cam*, cambium ring; *e*, epidermis; *m*, medullary ray; *p*, parenchyma; ph_1, primary phloem; sc_1, primary sclerenchyma; sc_2, secondary sclerenchyma; *st*, stone cells; *x*, xylem.

practically completes its development during the first year's growth. At the close of this period it occupies about half the thickness of the epidermis (*fig. 1*). During the elongation of the stem the epidermal cells retain the power of growth and division. Since their growth is largely in a longitudinal direction, the cell-division is mainly brought about by transverse walls, division by longitudinal walls being much

more infrequent. In an epidermis a year old, seen from the surface, the boundaries of the original epidermal cells can usually be distinguished. They are somewhat thicker than the secondary transverse walls, which in turn are thicker than the secondary longitudinal walls (*fig. 2*). With the formation of cork the epidermis is of course split longitudinally and soon begins to undergo disorganization. No trace of it is left in a tree 8^{cm} in diameter.

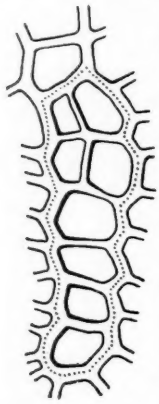


FIG. 2.—Surface view of epidermal cells. ×320. The dotted line represents the boundary of the original cell, which has undergone division.

The number of stomata produced varies greatly, but seems to be largely dependent upon external conditions. A rapidly growing tree, for example, in a moist locality has many stomata, while a slow-growing tree in dry soil develops very few. The stomata are depressed and the epidermal cells bounding the guard cells are somewhat modified, being longer and narrower than their neighbors (*fig. 3*). Most of the stomata are transverse to the axis upon which they are borne, a few are oblique, but apparently none of them occupy a longitudinal position. This is doubtless to be explained by the fact that the stomata are formed late in the development of the epidermis, the wall separating the guard cells representing one of the secondary transverse divisions of an epidermal cell. In the majority of cases the cells surrounding a stoma contain anthocyan, so that to the naked eye the stomatal region looks like a minute red speck in the epidermis. This peculiarity affords a ready means for detecting the stomata.

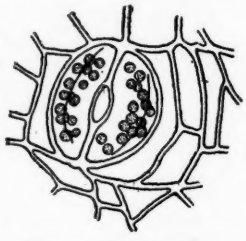


FIG. 3.—Stoma with surrounding cells, surface view. ×320.

Epidermal hairs are developed on very young twigs before the primary tissues are fully differentiated. They are simple and unicellular, with thickened walls, and scarcely extend below the cuticle (*fig. 4*). These hairs never persist through the first vegetative period, but dry up and fall away as soon as the cuticle begins to thicken. Their former position is often marked by

small concave depressions in the cuticle. The number of the hairs varies, and in a general way is inversely proportional to the number of stomata. Thus, in a moist locality few hairs are formed, while in a dry region they are very abundant. In a mesophytic area some trees bear few hairs, while others under the same conditions bear very many. It would appear from this that the production of hairs was primarily due to individual peculiarities of the tree in question and secondarily to the external conditions under which the tree developed.

FIG. 4.—Epidermal hairs on a twig one month old. ×50.

Outer cortex.

The outer cortex comprises everything external to the primary sclerenchyma except the epidermis. It is composed of a ground mass of parenchyma with scattered stone-cells. No crystal cells occur. With the formation of cork the outer cortex gradually becomes disorganized and eventually disappears.

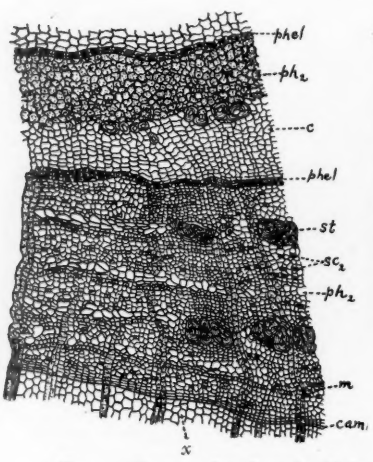
In cross section the parenchyma cells vary from elliptical to rectangular in outline, the long diameter running in a tangential direction (*fig. 1, p*). They vary considerably in size and some of the larger cells have their walls slightly lignified. Most of the cells, however, have thin walls, which may or may not be provided with simple pits. Many of the smaller cells contain starch and this is especially likely to be true of those which border the strands of sclerenchyma. The presence of ethereal oil in the parenchyma can be demonstrated by appropriate tests, but it does not seem to be localized in special cells. In all probability the oil represents an excretory product of the protoplasm of the parenchyma cells, and this fact would account for its general distribution.

The stone cells form a continuous or interrupted layer extending entirely around the stem (*fig. 1, st*). They sometimes lie next to the epidermis and are sometimes separated from it by one or two layers of parenchyma cells. The stone cells are at first circular in cross section but afterwards become flattened and assume an elliptical outline. In radial section they appear rectangular, being about three times as long as broad. Their walls are strongly thickened by deposits of

ligno-cellulose in distinct layers, and these are pierced by numerous simple and branched pits.

Primary medullary rays.

The primary medullary rays extend from the cambium to the outer cortex, the ray cells merging into the cortical cells without a distinct line of demarcation. The outer portion of the ray is of course directly differentiated from the meristem at the growing point, while the inner portions owe their existence to the activity of the cambium. Some of the cells in the outer portion retain their power of growth and division for several years, the majority of the dividing



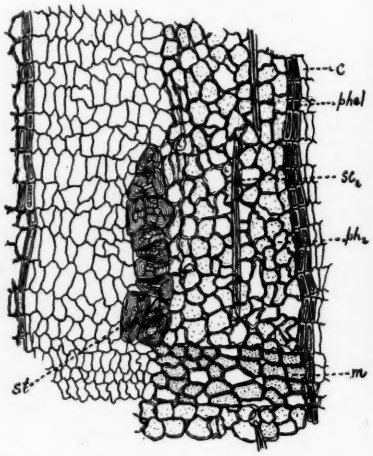


FIG. 5.—Cross section through old bast. ×25. FIG. 6.—Radial section through old bast. ×75. *c*, cork; *cam*, cambium ring; *e*, epidermis; *m*, medullary ray, *p*, parenchyma; ph_2, secondary phloem; *phel*, phelloderm; sc_2, secondary sclerenchyma; *st*, stone cells; *x*, xyiem.

walls being radial. Thus, in a stem one year old, the strands of primary sclerenchyma are separated by from two to five layers of cells, in a stem two years old by as many as fifteen layers, while in a stem four years old the number may be increased to thirty or more. Since the portions of the rays derived from the cambium do not undergo further divisions, they remain permanently from one to three cells in width. In consequence of these facts the rays gradually assume a T-shape

in cross section. This form is retained until the outer cortex has become disorganized, after which they appear like narrow bands (*fig. 5, m*). In radial section the rays are from four to fourteen cells across (*fig. 6, m*).

In most of the ray cells the walls are slightly thickened and provided with numerous simple pits. They usually contain starch and sometimes ethereal oil as well. When the cells are cut off by cork the starch disappears, showing that it is completely utilized; the oil, on the other hand, persists. Some of the ray cells between the strands of primary sclerenchyma become strongly sclerotic, and in some cases cells of this character completely bridge the space from one strand to another (*fig. 1*). They can be easily distinguished from the sclerenchyma cells, even in cross section, by their larger size and distinct lamination. In longitudinal section they appear short and resemble the stone cells of the outer cortex.

Primary bast.

The primary sclerenchyma occurs in well-defined bundles, averaging about fifty fibers apiece (*figs. 1, 8, sc_1*). Most of these bundles, in a radial direction, measure from three to eight cells across. In most of the fibers the wall is so strongly thickened that the cavity is reduced to a mere slit; in some cases, however, the thickening is less and this is especially likely to be true in the middle of a bundle. Apparently the deposition of ligno-cellulose upon the cell walls is not completed until the second vegetative period.

The primary phloem lies just within the primary sclerenchyma, between the latter and the secondary sclerenchyma, and forms a band from three to five cells across in a radial direction (*fig. 1, ph_1*). The sieve tubes are more or less completely separated from the sclerenchyma by a layer of phloem parenchyma. The cells of this layer tend to be rectangular in cross section, and their slightly thickened walls have numerous simple pits. The sieve plates separating the segments of the sieve tubes are nearly always somewhat oblique; they are supplemented by numerous lateral sieve plates, especially in the radial walls of the tubes. All of the sieve plates in the primary phloem soon become covered by deposits of callus. The companion cells conform to the usual type.

SECONDARY TISSUES.

Tissues derived from the cambium ring.

The tissues of the bark, regularly derived from the cambium ring, include the secondary sclerenchyma and the secondary phloem. In addition to these, scattered groups of stone cells, which should probably be considered a part of the phloem, also make their appearance. Of course the cambium also adds new elements to the primary medullary rays and brings about the development of the secondary rays (*figs. 1, 5*). The development of these various secondary tissues begins during the first vegetative period.

The fibers of the secondary bast do not form bundles. Some of them form interrupted layers arranged concentrically in the stem, others are scattered through the secondary phloem. The layers are usually but a single cell across and are separated from one another by several layers of phloem. The individual fibers are rectangular in cross section and about thirty times as long as broad; their walls are very strongly thickened (*figs. 1, 5, 6, sc_2*). When the bast fibers are cut off by cork all regularity in their arrangement disappears.

The sieve tubes of the secondary phloem, except those earliest formed, are arranged in interrupted, concentric layers, one or two cells across (*fig. 5, ph_2*). Many of the sieve tubes are in direct contact with the medullary rays, but very few of them adjoin the sclerenchyma fibers. The tubes exhibit essentially the same structure as those in the primary phloem. On account of their delicate walls they become practically indistinguishable when cut off by cork.

The bulk of the secondary phloem is composed of parenchyma. When first differentiated from the cambium the cells of this tissue are closely packed together, rectangular in outline, and destitute of intercellular spaces. As they become pushed outward, their outlines become more rounded and minute intercellular spaces appear. Their walls are fairly thin but are provided with simple pits. Until they are cut off by cork the parenchyma cells are arranged in layers, which lie among the layers of sclerenchyma and sieve tubes.

The groups of stone cells are irregularly scattered in the secondary bast but always abut against a medullary ray (*fig. 5, st*). Such a group in cross section is often larger than a bundle of primary sclerenchyma and is composed of larger elements. The stone cells are the

most conspicuous structures found in the inner bark, and are even more striking in appearance than those found in the outer cortex. In longitudinal section (*fig. 6, st*) they show the same outlines as in cross section (*fig. 7*) and are therefore isodiametric. Their strongly thickened walls show a very distinct lamination and their contracted cavities are connected by numerous simple and branched pits. Probably on account of poor material, these stone cells were not seen by MÖLLER.

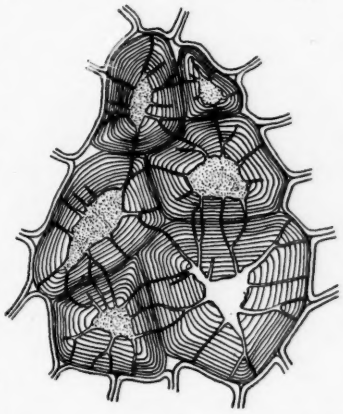


FIG. 7.—Stone cells from inner bark, cross section. ×450.

The phellogen and its derivatives.

The derivatives of the phellogen are the lenticels, the cork, and the phelloderm. The lenticel phellogen is the first to make its appearance; the primary cork phellogen is, at least in part, a direct extension of the lenticel phellogen; and the succeeding phellogens arise more or less independently from the deeper layers of the bark. The primary cork phellogen first appears on the south side of an erect stem and normally on the upper surface of a horizontal branch. From these regions it gradually extends laterally and usually forms a complete layer in the course of three or four years. The development, however, follows no definite rule. For example, in one eight-year old stem there was no cork on the north side except in the immediate vicinity of the lenticels, while in another stem of the same age there were five layers of cork on the south side and three on the north. These observations show that a phellogen layer may be active in one part although it has ceased to be functional in another. They also show that there is no definite relationship between the age of the stem or branch and the number of layers of phellogen. The early appearance of cork in the regions exposed to the sun is probably due to the fact that the sassafras is an intolerant species and that the cork protects the deeper tissues from sun scalding.

The primary lenticels are always formed directly beneath the stomata, following in this respect the general rule first enunciated by TRECUL.[3] Some of the lenticels never break through the epidermis but remain in an undeveloped condition. The lenticel phellogen arises from the layer of cells just within the epidermis. The thin-walled complementary cells are at first closely packed together. After about twelve layers of these cells are formed the epidermis is ruptured, and the complementary cells as they become exposed separate from each other and present very irregular and distorted outlines. The mature lenticel agrees with the second of the types described by DEVAUX[4] and shows no distinct layers of cork among the comple-

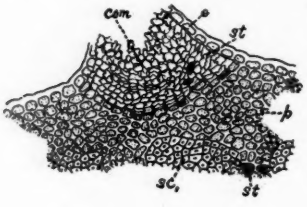


FIG. 8.

plementary cells (*fig. 8*). In some cases, however, a lenticel contains a few scattered stone cells (*fig.* 8, *st*). Secondary lenticels are developed from secondary phellogens and make their appearance in the splits of the bark. These lenticels break through the

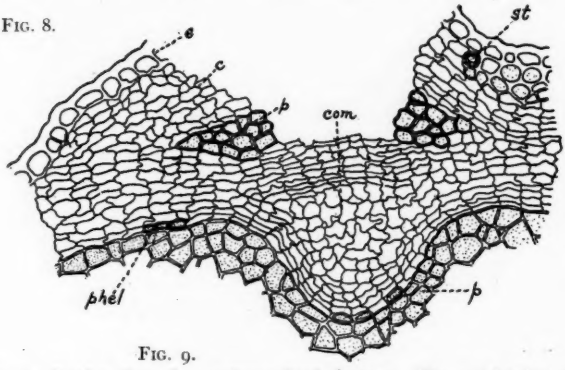


FIG. 9.

FIG. 8.—Section through a primary lenticel. ×55. FIG. 9.—Section through a secondary lenticel. ×60. *c*, cork; *com*, complementary cells; *e*, epidermis; *p*, parenchyma; *phel*, phelloderm; sc_1, primary sclerenchyma; *st*, stone cells.

layers of cork and parenchyma cells which enclose them and eventually exhibit the same structure as the primary lenticels (*fig. 9*).

Since the primary cork phellogen is a direct extension of the lenticel phellogen, it is never epidermal in origin but is always derived

[3] Compt. Rend. **73**:15. 1871. [4] Ann. Sci. Nat. Bot. VIII. **12**:61. 1900.

from the subepidermal parenchyma. In the majority of cases it arises from the layer of cells just inside the epidermis. Sometimes, however, it is derived from the second, third, or fourth layer, and this is always the case when stone cells are present next the epidermis. It thus frequently happens that the different parts of the phellogen do not all arise from the same layer of cells. The secondary layers of phellogen are largely derived from the parenchyma cells in the secondary phloem. When stone cells are present in the parenchyma the phellogen often bounds them on the inside. The phellogen forms concentric layers in the stem, but these layers are not altogether independent. In certain regions two layers will coalesce, in other regions they will be separated from each other by several layers of cells. Even the outermost of the secondary phellogens is more or less united with the primary phellogen.

The cork, as already noted by MÖLLER, is of the ordinary type. It consists of empty cells arranged in radial rows, and the walls are thin and suberised (*figs. 5, 6, 9, c*). In most cases from ten to twelve layers are formed by each phellogen. The structure of the cork is not uniform throughout the Lauraceae; in certain genera it consists of two kinds of cells arranged in more or less definite layers; namely, thin-walled cells and cells in which the inner tangential walls are thickened.[5]

The phelloderm in the sassafras forms a most characteristic feature of the bark. When derived from secondary phellogens it consists almost entirely of strongly flattened cells with thick lignified walls, provided with simple and branched pits. The flattening is in a radial direction, and the cells show the same rectangular outlines in both radial and transverse sections (*figs. 5, 6, phel*). The phelloderm is arranged in layers from one to three cells thick. The layer derived from the primary phellogen differs from the others in being composed of both thin-walled and thick-walled cells. In the case of lenticels the thick-walled phelloderm cells are few and scattered and are sometimes absent altogether. Lignified phelloderm does not seem to be of very frequent occurrence. According to J. E. WEISS[6] it is to be found in species of Cytisus and Philadelphus; KUHLA[7]

[5] See MÖLLER, Anat. der Baumrinden 103. 1882.

[6] Beiträge zur Kenntniss der Korkbildung. Denkschr. Königl. Bayer. Bot. Gesells. **6**: 61. 1890.

[7] Bot. Centralbl. **71**: 196. 1897.

describes it for *Ptelea trifoliata*, and SOLEREDER[8] notes its appearance in several genera of the Saxifragaceae other than Philadelphus. It therefore occurs in widely scattered families and probably has but little taxonomic significance.

SUMMARY.

Among the more interesting points brought out by this study are the following: the early thickening of the cuticle; the variation in the number of epidermal hairs and stomata; the early formation of cork in regions exposed to the sun; the stone cells in the outer bark, between the strands of primary sclerenchyma, and in the inner bark; the regular layers of thick-walled phelloderm derived from the secondary phellogens.

The writer is indebted to Professor ALEXANDER W. EVANS for criticism and advice.

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[8] Syst. Anat. der Dicot. 360. 1899.

BRIEFER ARTICLES.

THE DISTRIBUTION AND HABITS OF SOME COMMON OAKS.

WHEN doing some work in Wisconsin last year for the Arnold Arboretum, I found that *Quercus ellipsoidalis* E. J. Hill was well represented in the woods of the southeastern part of that state. It was originally described from trees growing in the vicinity of Chicago. It had been identified by those studying the flora near Milwaukee, and is quite abundant on the hills of the Kettle Range. It had also been recognized as distinct by those unfamiliar with botanical works, as disclosed by the common name "pin oaks." I had not before heard this name applied to any except *Q. palustris* Moench. The original description mentioned the usual but not universal drooping of the lower branches, as is quite common in the pin oaks. When finding it in some new locality I have sometimes been at a loss to decide which of the two species it was till the acorns were in hand. As the branches often come low down, they are apt to die as the trees grow older, and, breaking off a short distance above their base, leave stubs along the trunk, so characteristic of the pin oaks. This was freely the case in most of the trees seen in Wisconsin, and doubtless explains the local name.

Quercus palustris was not seen in any of the localities visited, nor did I learn of its presence from those familiar with the flora. In 1846 Dr. LAPHAM mentions its occurrence at Milwaukee in a book containing "A list of plants which have not before been noticed as indigenous to Wisconsin."[1] It was mentioned again by him in a paper on the "Plants of Wisconsin."[2] Though no locality is specified, it is understood from a prefatory statement to have been "within thirty miles of Milwaukee." If rightly identified (and Dr. LAPHAM was a careful and competent observer), it would seem to have disappeared. Yet there is the possibility that the tree with drooping lower branches with stubs along the trunk, and finely divided leaves, going by the common name of pin oak, was the one he alluded to, since the common name is added to the botanical in both of the above citations.

That botanists have been bothered by some form ascribed to *Q. palustris* or *Q. coccinea* is apparent from a statement of Dr. GEORGE VASEY in an

[1] Wisconsin: its geography and topography, history, geology, mineralogy, etc. Milwaukee, 1846, p. 73.

[2] Proceedings of American Association for the Advancement of Science 1849:19.

article on "Our native oaks." "It (*Q. palustris*) is found in low and swampy ground, and in general appearance much resembles the scarlet oak (*Q. coccinea*), and perhaps may yet have to be considered a variety of that polymorphous species."[3] Dr. VASEY resided for several years in northern Illinois, and could hardly have failed to see such forms of *Q. ellipsoidalis* as have led to its being confounded, by the common people at least, with the pin oak. But a typical scarlet oak is a tree of quite a different aspect from *Q. palustris*, and from its habitat would be more easily confounded with *Q. ellipsoidalis*. It is true that *Q. palustris* is commonly confined to low ground, though not always swampy, as along the margins of streams which have cut their beds deep down into the drift, leaving a high bank. Here the pin oak holds its place on ground that trends away from the stream and is comparatively dry. I have seen it along the Kankakee River move out of a swampy area to a bordering locality where the limestone was but a few inches below the surface. And although *Q. ellipsoidalis* commonly grows on dry or upland ground, it also occurs in lower, even wettish, localities, as by the borders of ponds and sloughs in low woods, becoming a near neighbor of the swamp white oak (*Q. platinoides*). Those seen in Wisconsin were on hills of till, or by the borders of lakes in the Kettle Range, or in soil of glacial drift. The least frequent of the biennial-fruited oaks associated with it seemed to be *Q. velutina*. *Q. coccinea* was quite common; *Q. rubra* the most abundant of all. In Illinois I have most frequently met with it in woods adjacent to streams not subject to overflow, the morainal hills being taken, when wooded, more by *Q. coccinea*, *Q. rubra*, *Q. velutina*, and *Q. imbricaria*, in prevalence somewhat in the order given.

It is therefore a matter of some doubt whether *Q. palustris* now occurs in Wisconsin. In Minnesota it is mentioned in UPHAM'S "Catalogue of the plants of Minnesota" on the authority of Dr. LAPHAM, the locality not being given; and on the authority of another collector as found in the region of the Upper Mississippi. I have not been able to get these statements verified. The pin oak of Minnesota may also be *Q. ellipsoidalis*. Professor SARGENT identifies this in specimens collected at the Falls of Minnehaha in 1878, and states that he himself first saw the species in 1882 at Brainard on the Red River of the North and at St. Paul.[4] In his report on the forest trees of North America, tenth census, volume 9, *Q. palustris* is given for Wisconsin; but in his account of the tree in the eighth volume of the *Silva*, this state is omitted from its range, as well as in his more recently published *Manual of the trees of North America*. Both Wisconsin

[3] The American Entomologist and Botanist **2**: 376. 1870.

[4] Silva of North America **14**:50. 1902.

and Minnesota are rather far north for its range. The farthest north I have found it in Illinois is in the town of Niles, just north of Chicago. Nor can I find any record of its occurrence in the more northerly counties of the state, where, if occurring at all, it is evidently very scarce. Dr. FRIEDRICH BRENDEL of Peoria, in an article on "The trees and shrubs of Illinois," says "The pin oak (*Q. palustris* Du Roi) I have never seen around Peoria, nor did, as I learn by letter, Mr. HALL in Menard County; it occurs in St. Clair and Marion Counties; in Wisconsin and Cook County (*fide* Mr. JACKSON)."[5] The credit to Wisconsin is doubtless due to Dr. LAPHAM, already cited. South of Chicago this oak appears in the southern part of Cook County in the town of Thornton, extending sparingly up Thorn Creek for a short distance, where it grows in company with *Q. ellipsoidalis*. It is most abundant east of the village of Thornton, making a good part of a wood growing in a soil of sandy peat, patches of sphagnum being common under the trees. Eastward it is found in occasional spots and in similar soils, and in the clayey soils of swamps in Lake and Porter Counties, Indiana. It comes into the dune region of Lake Michigan north of the village of Porter, in a sandy humus soil similar to that near Thornton.

Southward from here in Indiana it increases in frequency and abundance. In eastern Illinois it reappears south of the Thorn Creek localities after one crosses the range of hills here forming the water-shed of Lake Michigan basin (the Valparasio moraine), and is frequent along the Kankakee River at Momence.

Whether *Q. ellipsoidalis* occurs south of the most northern counties of Indiana there is no evidence at hand to show. Some time spent in examining the flora in the vicinity of North Judson and English Lake in Stark County did not reveal its presence, though the pin or Spanish oak was common along the Kankakee River there. Specimens of oaks sent from Bluffton in the eastern part of the state, a short distance south of Fort Wayne, lacked this species, but contained *Q. palustris* and *Q. texana* Buckley.

It is evident from this survey that *Q. ellipsoidalis* replaces to a large extent in the north of the Middle West the more southerly *Q. palustris*. But it is usually with a different and drier habitat, and an adaptability to a wider range of conditions. The boundaries of the two overlap in southern Michigan, northern Indiana, northern Illinois, eastern-central Iowa, possibly in southern Wisconsin. It may also be of interest to add that the northern bounds of another biennial fruited oak, the shingle oak (*Q. imbricaria*) correspond quite generally with those of *Q. palustris*.—

E. J. HILL, *Chicago*.

[5] Illinois Agricultural Report **1859**:596.

CURRENT LITERATURE.

BOOK REVIEWS.

Botanical dictionary.

In 1900 Jackson published the first edition of his *Glossary of botanic terms*, and last fall the second edition appeared.[1] We welcomed the first edition[2] as being a marked improvement upon any existing dictionary, and criticized but lightly the most obvious shortcomings. The compiler, most competent in many respects, had certain limitations by reason of his unfamiliarity with the content and consequently the terminology of morphology and physiology, and our general criticisms lay along these lines.

In judging the second edition one looks to see whether this weakness of the first has been removed, either by the author's own efforts, or by his associating with himself those who could supply the lacking knowledge. We find that the "revised and enlarged" of the title page means only that typographical and minor errors have been corrected in the plates of the first edition, and that a supplement of 68 pages has replaced the former "Additions during printing." One can overlook much in a first edition that cannot be forgiven in a second. Perhaps there will be a third with a resetting that will allow the necessary improvement. In that hope we may point out certain objectionable features that should receive attention.

In the first place it would be desirable to relegate to a separate list the many terms which have become obsolete, most of which are adopted from Lindley's *Glossary* and were antiquated in his day. Technical language changes rapidly, and such terms should be put into a museum and labeled as exhibits, if shown at all. We should then escape reading (except we were on antiquarian research bent) that an *ovule-tube* is "a thread-like extension of the amnios, rising beyond the foramen;" and, when we turn in wonder to see what the *amnios* in plants could have been, learning that it is "a viscous fluid which surrounds certain ovules at an early stage." We do not need often to know that *prosphyses* were "abortive pistillidia of the muscal alliance," and the youngster who has occasion to look for the word should learn that both it and its definition are mere survivals from a past century.

Second, space could be gained by omitting to define common words which have no technical meaning, such as congeries, enlargement, entangled, evapora-

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[1] Jackson, Benjamin Daydon, A glossary of botanic terms, with their derivation and accent. Second edition, revised and enlarged. 12mo. pp. 371. London: Duckwith & Co. (Philadelphia: J. B. Lippincott Co.) 1905.

[2] Bot. Gazette **31**: 68. 1901.

tion, minute, parallel, sex, tall, wound. All of these and many others are now included.

Third, more care should be taken to make definitions sufficiently general to include the various uses of the word, rather than so special as to refer only to particular uses. Thus, *conjugate* appears as an adjective, but not as a verb; *conjugating tubes* are defined in a special and unusual sense for the Rhodophyceae and not at all for the Conjugatae; for *pistil* is given (after a wholly erroneous definition in reference to spermatophytes) an obsolete sense which is restricted to the genus Andreaea, when in the same sense it was formerly applied to the archegonia of all mosses; *retardation* is not mentioned as other than the "influence of light on growth in certain structures;" and a *fat enzyme* is defined merely as an enzyme "converting olein into oleic acid and glycerin."

Fourth, greater accuracy is sadly needed. A few examples will illustrate this: *Galvanotropic*, "curvature, etc.;" *geotropism*, "the force of gravity as shown by curvature;" *geotaxis*, "movement in plants caused by gravity;" *stamen*, "a male sporophyll;" *pistil*, "the female organ of the flower;" *staminate*, "applied to flowers which are wholly male;" *oogenesis*, "the formation of the oosphere, the early stage of the ovule" (but oosphere is correctly defined later in the same paragraph!); *sap-pressure*, "the force exerted on passing upwards through the tissues;" *spermatogenesis*, "the development of the male elements, antherozoids, pollen-grains, and analogous bodies;" and so on.

Fifth (a matter for the publisher), the use of a more flexible paper and looser binding would contribute much to the handiness of the volume.—C. R. B.

MINOR NOTICES.

The dynamics of living matter.[3]—In the spring of 1902 Professor JACQUES LOEB was invited to deliver a series of lectures at Columbia University. In these lectures, eight in number, he presented the gist of his researches upon the dynamics of living matter. This book, forming the eighth volume of the Columbia University Biological Series, is a somewhat more complete survey of the field of experimental biology, says the author, than was possible in the lectures. In ten "lectures" he discusses the general chemistry and physical constitution of living matter, certain physical manifestations of life, the rôle of electrolytes, effects of radiant energy, heliotropism and other tropisms, fertilization, heredity, and regeneration.

Through the publication of his collected papers in English in the Decennial Publications of the University of Chicago[4] Professor LOEB'S point of view and the general results of his experimentation have become even more generally

[3] LOEB, J., The dynamics of living matter. Columbia University Biological Series VIII. 8vo. pp. xii + 233. *figs. 64.* New York: The Columbia University Press. 1906. $3.

[4] LOEB, J., Studies in general physiology, 1905.

known than from the originals. The topics named above are naturally those with which the author has chiefly concerned himself, and it cannot be said that the present volume contributes to general physiological literature anything new. The book is rather a new setting of the brilliant work and suggestive ideas of the author, that have previously enriched physiology, and with them is related the results of others in such wise as to round out the presentation. The lectures are readable and instructive, and they are especially commended to the attention of plant physiologists, who are too apt to pass over literature not strictly pertaining to plants.—C. R. B.

The problems of life.—The third part of this book[5] was issued last winter, and extends the author's fundamental hypothesis to the phemonena of fertilization and heredity. To him, if one admits the premises, the difficulties of these phenomena fade away like morning mists. The work does not cite definite observations, nor show, except in the most general way, how the known facts can be correlated by this theory; but it presents a clearly reasoned, logical series of deductions, which impresses the reader at once as too simple to be true. Moreover, one is naturally shy of a theory, which, beginning with an assumption regarding the molecular structure of protoplasm and the nature of assimilation, makes reproduction a necessary and inevitable consequence of these assumptions, while heredity likewise follows as a matter of course from the phenomena of fecundation. We were inclined to welcome the molecular conceptions of the first part,[6] as possibly embodying a fruitful theory, but we cannot follow the author as he widens and heightens his construction upon the acute fundamental assumption. Such inverted pyramids of logic can have no stability.—C. R. B.

Pfeffer's Physiology.—The third and last volume of this work was published about the middle of March.[7] It treats at length of the movements of plants, including the mechanical responses to various stimuli; and briefly of the production of heat, light, and electric tensions, and of the sources and transformations of energy. The translation, or rather the interpretation of the original, is of the same satisfactory character as in earlier volumes. As before, the editor has introduced supplementary and critical matter in footnotes; and in an appendix of eight pages he has supplied some important facts not mentioned in the first two volumes, and a summary of the more recent literature, especially that connected with the present volume. Throughout, his critical

[5] GIGLIO-TOS, ERMANNO, Les problèmes de la vie. III[e] partie: La fécondation et l'hérédité. 8vo. pp. viii + 189. Cagliari: The author, at the University. 1905. *fr.* 8.

[6] Cf. BOT. GAZETTE **31**:275. 1901.

[7] PFEFFER, W., The physiology of plants, a treatise upon the metabolism and and sources of energy in plants. Second fully revised edition; translated and edited by ALFRED J. EWART. Volume III. Imp. 8vo. pp. viii + 451. *figs.* 70. Oxford: The Clarendon Press. 1906. 21*s*.

care and acumen have enriched the already valuable work of the author, so that English readers are indebted to him for far more than a translation of peculiarly difficult German. To recommend the English form to all libraries and laboratories as a standard work of reference is, at this date, really quite superfluous.—C. R. B.

British flowering plants.—Under this title Lord AVEBURY,[8] better known as Sir JOHN LUBBOCK, has brought together a mass of desultory notes on various things connected with a great many plants. The author says that this work is "to describe points of interest in the life-history of our British plants; to explain, as far as possible, the reasons for the structure, form, and color; and to suggest some of the innumerable problems which still remain for solution." A glossary and an introductory chapter indicate that the book may be used by those with no botanical training; and perhaps it will be chiefly so used. Each species is taken as the occasion for the presentation of all sorts of facts and fancies and questions in reference to it, as though the author had emptied his note book under that head. There is no distinct organization and no adequate index; so that the botanist will simply have to "run on" to things.—J. M. C.

Spring flora of Ohio.—Under the title "Spring Flora," the botanical staff of Ohio State University has issued a manual for beginners and amateurs.[9] It is a revised edition of KELLERMAN'S "Spring Flora of Ohio," and its range has been extended so as to include Ohio and Indiana and the adjacent states. The time range extends from the opening of the season into the first part of June; and such difficult groups as grasses and sedges are not included. There is also a key to the trees and shrubs based on leaf and twig characters.—J. M. C.

Flora of Norway.—AXEL BLYTT'S completed *Handbook of the Norwegian Flora*, including the vascular plants, has been issued under the editorship of OVE DAHL.[10] In reality it has been in preparation since 1861, having been begun by the father, continued by the son, whose name is on the title page, and now finally edited by a third botanist. It is a model of compact and clear printing, excellent arrangement, and good text figures. The sequence is that of Engler and Prantl.—J. M. C.

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[8] AVEBURY, THE RIGHT HON. LORD, Notes on the life history of British flowering plants. 8vo. pp. xxiii+450. *figs.* 352. New York: The Macmillan Company. 1905. $5.00.

[9] KELLERMAN, W. A., GLEASON, H. A., and SCHAFFNER, J. H., Spring flora for beginners and amateurs. pp. xiii+188. Columbus, Ohio: Geo. W. Tooill. 1906. 75 cents.

[10] BLYTT, AXEL, Haandbog i Norges Flora. Efter forfatterens dod afsluttet og udgivet ved OVE DAHL. pp. xi+780. *figs.* 661. Kristiania: Alb. Cammermeyers Forlag. 1906.

Portraits of botanists.—In 1903 WITTROCK published a set of photographs of botanists selected from the collection at the botanical garden at Stockholm. A second series has now been issued,[11] containing full-page portraits of 100 botanists arranged chronologically from Aristotle to Goebel; and 51 additional plates, each containing 6 portraits. The biographic notes contain a large amount of information which must have been brought together with great labor.—J. M. C.

British Desmidiaceae.—In 1904 the first volume of this work was issued as a publication of the Ray Society. The second volume has now appeared,[12] containing the genera Euastrum (46), Micrasterias (18), and Cosmarium (50). —J. M. C.

NOTES FOR STUDENTS.

Regeneration.—The number of recent papers dealing with regeneration indicates a marked activity in this field of investigation. The work of IRMISCH and others has made us familiar with the fact that the hypocotyls of a number of plants can produce adventitious buds. In some cases these occur normally, but in others only in the presence of more unusual conditions of growth. BURNS and HEDDEN[13] have investigated these conditions, using seedlings of *Linaria bipartita splendida*, *Antirrhinum majus*, and *Linum usitatissimum*. They confirm KÜSTER'S results that when the cotyledon or the main vegetative tip is cut away the tendency toward the development of adventitious buds is greatly increased. On uninjured seedlings of Antirrhinum which do not stand erect but are horizontal, buds arise only on the upper side, and when these plants are fastened so that they must remain erect they produce no buds. The effect of a moist atmosphere is to increase the number of buds and the rapidity of their development. The same is true of higher temperature. The older parts of the hypocotyl have a much greater capacity to produce buds than the younger parts, and there is no tendency at all to bud production on the part of the hypocotyl still elongating. Gravity seems to have no influence. Light, on the other hand, is a necessary condition, for in one-sided illumination buds appear only on the illuminated side, on a klinostat in the light on all sides equally, and in the dark not at all. Experiments are mentioned which indicate that wounding is not a cause of the regeneration here. The explanation of the phenomena mentioned as given by the authors is that "when the cotyledons are removed

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[11] WITTROCK, VEIT BRECHER, Catalogus illustratus iconothecae botanicae horti Bergiani Stockholmiensis; notulis biographicis adjectis. Acta Hort. Berg. **3**:No.3. pp. xciii+245. *pls. 151.* 1905.

[12] WEST, W., and G. S., A monograph of the British Desmidiaceae. Vol. II. pp. x+206. *pls. 32.* London: Ray Society. 1905.

[13] BURNS, GEORGE P., and HEDDEN, MARY E., Conditions influencing regeneration of the hypocotyl. Beih. Bot. Centralb. **19**:383–397. 1906.

or cease to function, their work is taken up by the epidermis. The cells of this develop a vast amount of chlorophyll and all movement is to and from them." "Only those cells exposed to light function as cotyledons, and hence all flow of material is to and from the lightest side. Light is then an indirect cause of the location of the buds, while the principal factor is determining the location in relation to movements of food materials in plants." This would make it entirely a question of nutrition, a rather unusual condition, for in most cases of regeneration in plants, and in animals too, regeneration will occur while the parts concerned are but poorly nourished.

FIGDOR[14] cut off the apices of young fern fronds prependicular to the median axis and very close to the tip, removing only a fraction of a millimeter of the tip. Replacement occurs slowly, but the new tips become forked, two apical cells forming, one on each side of the midrib. The two sides extend outwards, leaving the midrib sunken in the center. By cutting very young fronds with a median longitudinal cut about 5^{mm} deep, regeneration of each half occurs, and a subsequent branching of the frond is obtained. The fern used was *Scolopendrium Scolopendrium*, a variety of which (*daedalea*) occasionally occurs in nature with forked fronds, and FIGDOR considers this probably due to wounding of the tips by insects and subsequent regeneration.

HILDEBRAND[15] has continued his studies on regeneration in Cyclamen, and presents further interesting observations. Two forms are mentioned, *Cyclamen Miliarakisii* and *C. creticum*. On the former, when the leaf blade of the cotyledon is removed, leaving the petiole, there arise a little below the place of removal, from a point on one side of the petiole, four small leaves, each having the form of the cotyledon, and the four together aggregating the size of the blade removed. Each is borne on a distinct petiole of sufficient length to bring the blades out far enough to prevent shading each other. In this the author sees an exceptional example of the principle of utility in the development of plant structures. In the other species, *C. creticum*, HILDEBRAND observed a plant having no cotyledons, but upon which, arising from the center of the tuber, were three leaves with long petioles. Each blade was almost one-third the size of the round cotyledon-blade, and in form intermediate between the cotyledon and the foliage leaves. Investigation showed that the cotyledon had been destroyed to the base, and these three leaves arose together from the axis of the plant just below the point of attachment of the cotyledon. They originated as entirely new structures, replacing cotyledons, and were intermediate in form between these and the later leaves.

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[14] FIGDOR, W., Ueber Regeneration der Blattspreite bei *Scolopendrium Scolopendrium*. Ber. Deutsch. Bot. Gesell. **24**: 13–16. 1906.

[15] HILDEBRAND, FRIEDRICH, Ueber eine eigentümliche Ersatzbildung an einem Keimling von *Cyclamen Miliarakisii* und einem anderen von *Cyclamen creticum*. Ber. Deutsch. Bot. Gesell. **24**: 39–43. 1906.

SETCHELL[16] gives an account of regeneration among kelps. He distinguishes between physiological and restorative regeneration, applying the terms in the same sense as used by MORGAN. In physiological regeneration he notes two kinds, continuous and periodic. In the former the continuous growth of the meristematic tissue at the base of the blade keeps pace with the constant breaking off at the tip due to wave action, and so the blade retains a constant length. In other species this growth is periodic, occurring in the spring and in the autumn. The growth of a new blade lifts the old one from the top of the stipe and it is rapidly eroded, the new one thus taking its place. Restorative regeneration involves the development of new branches and occurs as a result of wounding. If the stipe is broken off a new blade is formed at its apex. Wounds along the surface of the stipe result in new blades arising at the points. A vertical wound at the tip results in a splitting of the blade and the appearance of forking. The observations are followed by a discussion in which the author contends that the phenomena of regeneration are to be explained best by the assumption of a flow of materials toward the parts concerned. He does not consider it necessary to assume a special organ-forming material, the important thing being the control of the flow of already organized food materials. This control of the food substances is due to certain cells being able to exert a stronger "pull" upon them than others.

As this idea is so commonly used in explanation of regeneration, the reviewer cannot forbear remarking that it removes one difficulty only to incur a greater one. Soluble food materials, in common with all other diffusible solutions in plants, move toward the region of least concentration, and if there is a more rapid flow of substances toward any region, it indicates that these are being taken out of solution there, either by being used or otherwise transformed. The more active the use, the lower will be the concentration, and the more active the flow will tend to be toward that point. The increased activity of the cells, either in using up by growth or otherwise transforming the food substances, must precede any special flow (that is, apart from a general diffusion in all directions) of these substances into any particular region. The movement, or, if preferred, the "flow" of soluble substances (other than a general diffusion) toward special cells is necessarily a result and not the cause of their activity.

MIEHE[17] has used an interesting method of studying the behavior of isolated cells, especially in their relation to polarity. When a tissue is plasmolyzed, the continuity of the protoplasm is broken and the protoplasts become separated from one another. In this way a plant may be divided into its individual cells, and the behavior of these, each acting independently, can be studied. MIEHE used this method on a marine Cladophora. The plants were plasmolyzed in

[16] SETCHELL, WILLIAM ALBERT, Regeneration among kelps. Univ. Calif. Publ. Bot. **2**:139–168. *pls. 15–17.* 1905.

[17] MIEHE, HUGO, Wachstum, Regeneration und Polarität isolierter Zellen. Ber. Deutsch. Bot. Gesell. **23**:257–264. *pl. 4.* 1905.

a strong salt solution (16.2%), and then transferred gradually to normal sea water. In nearly all cases the protoplasts regained almost entirely their original size, a few remaining in the plasmolyzed form. An active growth promptly set in, by which the form of the alga was entirely changed. First the protoplasm of the last-mentioned cells, by means of rounded or tube-like outgrowth, finally filled up the original space within the cell walls. Then all the cells grew in this way: the basal end of the cell pushed into the cell below in the form of tubes, often growing between the protoplasm and the cell wall; or occasionally the whole cell bulged into its neighbor. When one cell is dead, the next above grows in and fills it completely. Often from the lower angles of the cells tubes grow downward into the cells below. Many of these tubes assume the character of rhizoids. All of these outgrowths occurred at the basal end of the cell, not a single one from the apical end. Later, unless the upper cells begin to produce branches, they do so entirely from the apical end. A very striking polarity of the cell is thus seen.

Some interesting results on polarity and organ-formation on *Caulerpa prolifera* have been contributed by JANSE.[18] This plant he shows to possess a well-marked polarity in the formation of "leaves" and rhizoids, and also in the streaming of the protoplasm, which is always from the apex toward the base. Following a wound there appears to be a division in the protoplasm, the chlorophyll-bearing portion separating from a colorless turbid portion. It is the latter, according to JANSE, that occasions the formation of new organs. The polar phenomena he considers dependent upon a flow of energy in which the force acts always in the direction of the base. This stream of energy he calls the "basipetal impulse." The opposite, an acropetal impulse, was not to be detected, and JANSE concludes that "the lack of an 'acropetal impulse, implies the lack of a second pole at the organic tip." Thus we have a polarity with only one pole. The author applies this conception to polarity as seen in the higher plants. The point of view is more interesting than convincing.

TOBLER[19] uses some observations on Polysiphonia and Ceramium as the basis of a lengthy and rather elusive discussion on regeneration and polarity. He sees a difference in the lower and higher plants in respect to polarity, which he considers rests on the differentiation of tissues, and accompanies the division of labor in the plant.—W. B. MACCALLUM.

Roots of Monocotyledons.—LINDLINGER[20] has reopened the question of the place of origin of the secondary growth shown by the roots of some mono-

[18] JANSE, M. J., Polarität und Organbildung bei *Caulerpa prolifera*. Jahrb. Wiss. Bot. **42**:394–460. *pls. 9–11*. 1906.

[19] TOBLER, FR., Ueber Regeneration und Polarität sowie verwandte Wachstumsvorgänge bei Polysiphonia und andern Algen. Jahrb. Wiss. Bot. **42**:461–502. *pls. 12–14*. 1906.

[20] LINDLINGER, L., Zur Anatomie und Biologie der Monocotylenwurzeln. Beih. Bot. Cent. **19**:321–358. 1905.

ciently to permit the annual volumes to be bound. Heretofore these volumes have been represented by the annual appendices, which led to the current gibe that the *Bulletin* had succumbed to appendicitis. The most curious illustration of "closing up ranks" is the volume for 1900, the body of which consists of 32 pages, now issued as nos. 157–168, and which were necessary as a preface to the four appendices.

PROFESSOR W. A. KELLERMAN recently returned from his second collecting trip to Guatemala. On account of quarantine regulations (because of yellow fever) he was obliged to return three weeks before the time set. The party traversed the entire country from east to west and went up as far as Quetzaltenango (alt. 2500^{m}). Collections were made about Lake Amatitlan and also at the still more beautiful Lake Atitlan, and on the ascent of three volcanoes. Perhaps ten times as many species of parasitic fungi were gathered as in the same time last year, and the collections seem to contain many new species.

DR. F. CAVARA reports as reasonably successful the attempts to establish an alpine garden on the slopes of Mt. Etna. It is located behind the Casa Cantoniera at an altitude of 1880^{m}, the first cultures at 1440^{m} having failed on account of the heat and drought. About 150 species are now thoroughly established, and nearly 400 more are more or less sucessfully grown. The garden is surrounded by a stone wall which mitigates the violence of the winds. Cisterns and snow magazines (there are no streams) eke out the scanty supply of rain in the growing season, which in 1904 was 56^{mm} in May, June, July, and August. The director is to be congratulated on overcoming the many difficulties and solving so many of the problems which confront him in this undertaking. The garden has been christened *Gussonea*, in honor of "un valoroso studioso della flora sicula."

GENERAL INDEX.

The most important classified entries will be found under Contributors, Personals, and Reviews. New names and names of new genera, species, and varieties are printed in **bold face** type; synonyms in *italic*.

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